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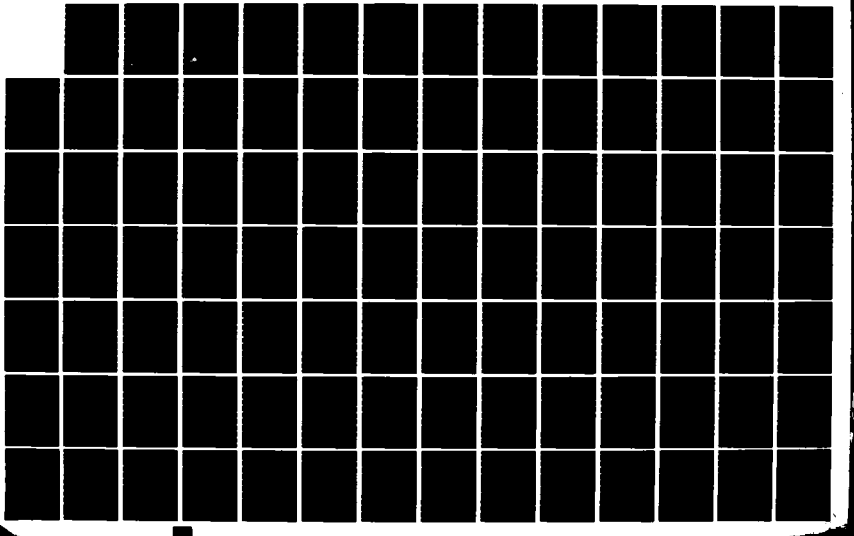

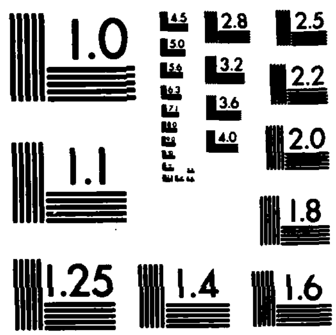

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TROPICAL WEATHER SYSTEM AND OCEAN MODELING

FINAL REPORT 83-1155

Contract N00014-82-C-2306

SCIENCE APPLICATIONS, INC.

TROPICAL WEATHER SYSTEM AND OCEAN MODELING

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TROPICAL WEATHER SYSTEM AND OCEAN MODELING

FINAL REPORT SAI 83-1155

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This final technical report documents the research efforts in the numerical simulations of tropical weather systems carried out under the auspices of ONR Contract N00014-82-C-2306, for the Atmospheric Physics Branch, Space Science Division, of the Naval Research Laboratory (NRL).

Our research efforts mainly concentrate in two major study areas: the interactions between two tropical cyclones and the construction of an axisymmetric ocean model. The research in both of these areas has been completed and reported in two articles. A paper entitled "A Numerical Study of the Interactions Between Two Tropical Cyclones" was accepted by the Monthly Weather Review and is to be published in the 1983 September issue. The draft of a second article on the ocean model has been completed. Both articles are included as Appendices in this final report. We have also attached a listing of the computer code of the ocean model, which is also stored in and accessible from the TI-ASC of NRL. Here, a brief summary of the study result will be given.

The interactions between atmospheric vortex pairs are simulated and studied with a nondivergent barotropic model and a three-dimensional tropical cyclone model (NRL/SAI mesoscale model). Numerical experiments with nondivergent barotropic vortex pairs show that the relative movements of the vortices are sensitive to the separation distance

and the characteristics of the swirling wind of the vortex. No observed mutual attraction is found in any of the nondivergent, barotropic vortex pairs tested.

Results from the 3D NRL/SAI tropical cyclone model show that on a constant-f plane with no mean wind, the movements of the two interacting tropical cyclones consist of a mutual cyclonic rotation, attraction, and eventual merging, in agreement with Fujiwhara's description. The displacement of one interacting storm in the mutual rotation is proportional to the combined strength of the binary system, but inversly proportional to the size of the storm and to the square of the separation distance. The rate of merging is related to the development of a mean secondary circulation on the radial-vertical plane, and is quite independent of the strength of the two tropical cyclones.

The latitudinal variation of the Coroilis parameter adds a northwest beta drift to the trajectories. Depending on their relative strength and location, the beta drift can either speed up the merging process or separate the two interacting tropical cyclones.

The axisymmetric ocean model consists of primitive equations for the conservation of momenta in three spatial dimensions and the buoyancy. A Boussineq assumption is made so that the background stratification is kept constant, the horizontal and vertical diffusion is of the Fickian type.

A leapfrog temporal integration is employed. The grid is fully staggered as Arakawa C type. The system is non-hydrostatic, the resultant elliptic equation for the pressure is solved by a stablized error vector propagation technique. The basic equations, the finite differencing form, and boundary conditions are discussed in detail in the attached Appendix.

APPENDIX I

A NUMERICAL STUDY OF THE INTERACTIONS BETWEEN TWO TROPICAL CYCLONES

A Numerical Study of the Interactions Between Two Tropical Cyclones

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ABSTRACT

The interactions between atmospheric vortex pairs are simulated and studied with a nondivergent barotropic model and a three-dimensional tropical cyclone model.

Numerical experiments with nondivergent barotropic vortex pairs show that the relative movements of the vortices are sensitive to the separation distance and the characteristics of the swirling wind of the vortex. No mutual attraction is found in any of the nondivergent, barotropic vortex pairs tested.

Results from the 3D tropical cyclone model show that on a constant-f plane with no mean wind, the movements of the two interacting tropical cyclones consist of a mutual cyclonic rotation, attraction, and eventual merging, in agreement with Fujiwhara'a description. The displacement of one interacting storm in the mutual rotation is proportional to the combined strength of the binary system, but inversly proportional to the size of the storm and to the square of the separation distance. The rate of merging is related to the development of a mean secondary circulation on the radial-vertical plane, and is quite independent of the strength of the two tropical cyclones.

The latitudinal variation of the Coriolis parameter adds a northwest beta drift to the trajectories. Depending on their relative strength and location, the beta drift either speeds up the merging process or separates the two interacting tropical cyclones.

1. INTRODUCTION

When two tropical cyclones are present simultaneously in the same region, it is often observed that they rotate around each other with decreasing separation between them in the absence of large scale wind flow (Fig. 1). The phenomenon was made well-known by Fujiwhara (1921), and is therefore referred to as the Fujiwhara effect. By laboratory experiment and geophysical observation, Fujiwhara (1923, 1931) demonstrated that the relative motion of two counterclockwise vortices was a counterclockwise rotation. Haurwitz (1951) examined several tropical cyclone pairs by introducing the concept of center of mass around which the two tropical cyclones rotate about each other. By approximating the circulation around a tropical cyclone with that of a Rankine vortex, Haurwitz (1951) derived a relationship between the rotation rate and the sum of the total mass circulation of the two tropical cyclones. Many discrepancies were found when he applied the relationship to observations. Haurwitz attributed the discrepancies to the influence of large scale flow and lack of data, which led to deficiency in analyses.

Hoover (1961) studied binary tropical cyclones in both the Atlantic and Western Pacific Oceans. He found that the interaction between tropical cyclone pairs in the Western Pacific Ocean agrees with Fujiwhara's description while those pairs in the Atlantic Ocean rotated in an anticyclonic sense. He suggested that the different large scale atmospheric flow patterns in the two basins may have caused the binary systems to behave differently. The influence of the large scale flow was also noted by Liu and Wang (1966). They found that two interacting tropical cyclones in the Western Pacific are not always attracted to each other when there are strong shears in the environmental

flow. Recently, Dong and Neumann (1982)[1] found that storm pairs exhibiting behavior most in accordance with Fujiwhara's description were located in the Intertropical Convergence Zone where horizontal shears in large scale flow are negligible. They suggest that the effects of environmental flows be filtered before the real Fujiwhara effects can be determined. But to define and remove the large scale flows from observational data is difficult to accomplish.

Over the 35 year period 1946-1981, storm pairs known to have interactions averaged 1.5 annually in Western North Pacific and 0.33 annually in the Atlantic (Dong and Neumann, 1982). The presence of binary interacting has been noted to have contributed to forecast errors of tropical cyclone tracks (Brand, 1970; Jarrell et. al.; 1978; Neumann, 1982). Forecasting as well as analyzing a single tropical cyclone is often hindered by the paucity of observational data in the tropical cyclone basin (Neumann, 1982); the presence of two storms in close proximity can further compound the difficulties.

The purpose of our study is to investigate the interactions between two tropical cyclones by numerical simulations. Because the spatial resolutions of the models are better than the current observational network, and because numerical models can be controlled to produce "clean" results void of undesirable factors, analyzing realistic numerical simulations can sometimes result in a better isolation and understanding of the phenomenon than can be acheived from an observational approach. In this paper we will first determine the role of vorticity advection between the two vortices. For this purpose, a nondivergent, barotropic model is introduced to test two types of vortex pairs with different

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[1]Dong, K. and C. J. Neumann, 1982: On the relative motion of binary tropical cyclones. Regional Scientific Conference on Tropical Meteorology, Tsukuba Ibaraki, Japan, Oct. 1982.

swirling winds. These barotropic tests will be presented in Section 2. In Section 3, three-dimensional simulations of the interactions between two diabatically driven tropical cyclones on a constant-f plane and with variable f will be discussed. Our findings will be summarized in Section 4.

2. INTERACTIONS BETWEEN NONDIVERGENT, BAROTROPIC VORTEX PAIRS

In this section, we investigate the interactions between nondivergent barotropic vortex pairs. Through the interactions of such vortex pairs, we can determine the contribution of horizontal advection of vorticity, because in such a system advection is the only mechanism for interaction. A description of the nondivergent, barotropic model will be presented first, and the experimental design and the results will then be discussed.

a. Nondivergent Barotropic Model

The simple non-divergent, barotropic model can be described as

$$\frac{\partial}{\partial t} \nabla^2 \psi = -\underset{\sim}{V}_\psi \cdot (\nabla^2 \psi + f), \text{ and} \tag{1}$$

$$\underset{\sim}{V}_\psi = \hat{k} \times \underset{\sim}{\nabla} \psi \tag{2}$$

where f is the Coriolis parameter, ψ is the stream function, $\underset{\sim}{V}_\psi$ is the nondivergent wind, and $\hat{k}$ is a vertically pointing unit vector. The boundary conditions for (1) and (2) are Neumann, i.e., $\nabla^2 \Psi = 0$ at boundaries. The model has 51 x 51 grid points with a uniform horizontal resolution of 50 km. The relevant elliptic equation

$$\nabla^2 \psi = \zeta \tag{3}$$

where the relative vorticity is defined by

$$\zeta = \hat{k} \cdot \underset{\sim}{\nabla} \times \underset{\sim}{V}_{\psi}, \tag{4}$$

is solved by a stabilized error vector propagation method (Madala, 1978).

b. Experimental Design

The major application of the nondivergent barotropic model is to determine the effects of separation distance and the radial distribution of tangential winds on the interaction of the two vortices. Two kinds of wind distributions were tested. The first kind (type A) of vortex is defined by its cyclonic swirl wind v_o as function of radius r from the vortex center

$$v_o = \begin{cases} Ar\left(1 - \sin\dfrac{\pi r}{r_o}\right), & 0 \le r \le r_o \\ 0, \text{ otherwise} \end{cases} \tag{5}$$

where constant $A = 4 \times 10^{-4}\ s^{-1}$ and $r_o = 400$ km. Equation (5) yields a maximum swirl of $\sim$26 m s^{-1} at r = 150 km and a maximum vorticity $\zeta \cong 7.2 \times 10^{-4}\ s^{-1}$ at r = 0. We note that there is a cutoff of v_o at r_o.

The second kind of vortex (type B) is defined as

$$v_o = Br \exp\left(-\frac{r^2}{r_e^2}\right) \tag{6}$$

where the e-folding distance r_e is 150 km. By letting the constant $B = 3.6 \times 10^{-4}\ s^{-1}$, (6) yields a vortex with similar strength as that described by (5) with maximum swirl of $\sim$29 m s^{-1} and a maximum $\zeta \cong 7 \times 10^{-4}\ s^{-1}$. Type B vortex differs from Type A in that there is no cutoff of swirl. Fig. 2 compares the radial distributions of relative vorticities described by (5) and (6).

Four initial separation distances (300, 400, 600, and 1000 km) have been tested for each type of vortex pairs. All intergrations with the barotropic model are performed with constant $f = 4.37 \times 10^{-5}\ s^{-1}$.

c. Results

Fig. 3 shows the trajectories of storm pairs having two types of swirl wind at four separation distances. It is very clear from Fig. 3 that the smaller the separation distance the faster the mutual transport. For instance, at a separation distance of 1000 km, neither type A vortex pair (with swirl cutoff at r = 300 km) nor type B vortex pair can induce mutual motion. But at a separation distance of 400 km, they move at a speed of $\sim$400 km day^{-1}.

It is also evident that the mutually-induced motions of type A and type B vortices are very different, in spite of the values of constants for A and B which were chosen to give vortices of similar strength. Furthermore, the trajectories of type A vortex pairs are more anticyclonic. This may be a result of the fact that type B vortices have positive vorticities at $r \leq 200$ km whereas the vorticities of type A vortices change sign at r = 150 km (Fig. 2). Only vortex pairs at small separation distances rotate in a cyclonic fashion because they interact with positive shears. The motion of vortices in our model can only be caused by the advection of vorticity, the shear in one vortex can very much determine the movement of the other. These results indicate that the mutual motion of two interacting nondivergent, barotropic vortex pair are quite sensitive to the charateristics of the swirl winds.

In all the experiments illustrated in Fig. 3 the storm pairs drift apart, there is no mutual attraction as observed in some interacting typhoons. This suggests that the observed mutual attraction in typhoon pairs may be due to

the divergence and/or convergence that is not included in the barotropic model. Indeed, complicated diabatic processes in tropical cyclone such as long wave radiation, surface boundary layer effects and moist convection generate convergent flow in lower troposphere and divergent flow in upper troposphere. The irrotational component of the vortex circulation may be responsible for the occurrence of the observed cyclonic rotation and mutual attraction.

3. INTERACTIONS BETWEEN TROPICAL CYCLONE PAIRS

We have seen that nondivergent pairs do not cause a mutual motion similar to the description of Fujiwhara. The observed Fujiwhara effects may be due to dynamics that can only be resolved by a more complete model. To see that, we will simulate the interactions between two diabatically driven tropical cyclones with a three-dimensional model.

a. Three-dimensional Tropical Cyclone Model

The baroclinic model is identical to the one in Chang and Madala (1980) and Chang (1982), except for parameterization of the latent heating. The governing equations are in surface-pressure-weighted flux form for conservation of momentum, temperature and water vapor. The normalized pressure $\sigma = p/p_s$ is the vertical coordinate, where p_s is the surface pressure. The system is assumed hydrostatic. The bulk boundary layer parameterization is based on a generalized similarity theory (Chang, 1981). The model has 51 x 51 horizontal grid points with seven sigma layers in the vertical. The horizontal resolution if $\frac{1}{2}^{o}$ in both the latitudinal and longtitudinal directions. The east-west boundaries are cyclic. The boundary conditions at the north and south boundaries are such that the second derivatives of thermodynamic variables

normal to the boundaries vanish. In addition, diffusion coefficients are increased near the north and south boundaries to damp numerical noise there.

Kuo's parameterization was used in Chang and Madala (1980) and Chang (1982), but a prescribed heating is applied in this model as done by Anthes (1971) in a axisymmetric model. The heating rate here is defined as

$$\dot{Q}(r,\sigma) = \begin{cases} \dot{Q}_o \cos\left(\frac{\pi r}{2R}\right) \sin\left[\pi(\sigma-0.1)\right], & \text{for } r \leq R,\ 0.1 \leq \sigma \leq 0.9 \\ 0, & \text{otherwise} \end{cases} \tag{7}$$

where r is the distance between a grid point and the low pressure center, and R = 300 km is the limit of the heating function. Two values of $\dot{Q}_o$, 100 K day^{-1} and 200 K day^{-1}, have been used in various numerical experiments to define the weak and strong tropical cyclones, respectively. The vertical and horizontal distributions of the heating pattern described in (7) are illustrated in Figs. 4 and 5. The vertical heating distribution is similar to that of the differences between temperatures in convective clouds (T_c) and the environment (T) in a mean hurricane season sounding for the Gulf of Mexico as computed by a one-dimensional cloud model (Anthes, 1977, Fig 4a). The horizontal heating distribution agrees with the mean rainfall rate inferred from satellite observation in a typhoon (Adler and Rogers, 1977), except for the observed smooth fall-off at $r \geq 300$ km. No effort is attempted to simulate the eye because of the model horizontal resolution.

The heating prescribed by (7) nevertheless generates realistic circulations for tropical cyclones. Figure 6 shows the radial distribution of the quasi-steady wind speeds at the sixth ($\bar{\sigma} = 0.85$) and seventh ($\bar{\sigma} = 0.965$) model layers after 24 h of heating with $\dot{Q}_o = 200$ K day^{-1}. The wind speeds have a peak at $r = 1^o$ and decrease gradually outward without discontinuity

at r = R = 300 km.

We note however that by using the prescribed heating in (7) the effects of the interaction between the two cyclones on the scale of the cumulus convection cannot be adequately simulated. In reality the momentum field in each storm, which affects the cumulus convection, can be modified by the proximity of another storm. A change in the cumulus convection in each storm may alter the storm's intensities, which can in turn affect the interaction between the two tropical cyclones. But these feedbacks may be secondary and are only important when the separation of the two storms is small. As a preliminary study, the more economical, prescribed heating is used to investigate the first order effects in the interaction.

b. Experimental Design

The tropical cyclone pairs in all numerical experiments (Table 1) with the 3D model are dynamically initialized by a 24h stationary heating at two locations, i.e., by applying (7) at two fixed grid points for 24h. Dong and Neumann (1982) found that in real cases when the separation distances are less than 11 degree of latitude, cyclonic rotation predominates. Therefore, the two fixed grid points for the stationary heating are set ten degree longitude apart in all experiments to ensure the occurrence of interaction. After the dynamic initialization period, the heating patterns are allowed to follow the low pressure centers. In Exps. 1-3 we simulate the Fujiwhara effects in zero large scale winds on a constant-f plane for strong-strong (Exp. 1) weak-weak (Exp. 2) and strong-weak (Exp. 3) storm pairs. Exp. 1 and 3 are repeated in Exp. 5 and 6 on a real variation of f. There is only one single tropical cyclone in Exp. 4 to help isolate the effect of the beta-drift. Unlike on a

Table 1: List of three-dimensional Numerical Experiments

Exp.	$\dot{Q}$ (K day^{-1})		$f(s^{-1})$	Characteristic
	Storm A	Storm B		
1	200	200	4.37×10^{-5}	strong-strong interaction
2	100	100	"	weak-weak interaction
3	100	100	"	weak-strong interaction
4	200	-	variable f	beta drift
5	200	200	"	strong-strong interaction
6	100	200	"	weak-strong interaction
7	200	100	"	strong-weak interaction

constant-f plane where geophysical orientation is not meaningful, the interactions with real f for a weak (west)-strong (east) pair and strong (west)-weak (east) pair are quite different, as we shall see later, thus Exp. 7 is conducted to study the latter situation.

c. Results on a Constant-f Plane

Fig. 7 shows the surface pressure field at 24, 48, 72, and 96h for Exp. 1. The southward displacement of storm A (west) and the northward displacement of storm B (east) at 24h indicate that their interaction has already caused the two storms to begin to rotate cyclonically in spite of the stationary heating. The merging of the two storms progresses with the merging of the outer isobars as observed (Fig. 1). By 96h, only the 996 mb isobars show two separate low pressure centers. The pressure at the center point of the model decreases by 10 mb while the approaching of the two initial low pressure centers between 24-96h can only account for a pressure decrease of 2 mb. This indicates that the mutual rotation and merging involve dynamics more complicated than merely advective processes.

Exp. 1-3 are integrated with a constant f. Therefore the orientation has little meaning and the results are independent of the absolute initial positions of the storms. Fig. 8 shows the trajectories of the storm centers in Exp. 1, in which two strong model tropical cyclones are of the same strength. The trajectories show that the two storms rotate about each other in a cyclonic fashion before the coalescence at 102h. The two trajectories are symmetric about the center of mass, which coincides with the center of the model domain. Superimposed on the symmetric rotation is a convergence of the two tropical cyclones. The distance between the two storms decreases from $\sim$1024 km at 24h to $\sim$612 km at 96h. The symmetry remains until 102h when the two heating

patterns overlap and one single large area of low pressure is formed.

Exp. 2 is identical to Exp. 1 except that the heating rate is reduced by one half. The cyclonic trajectories (Fig. 9) are still remarkably symmetric about the center of mass. Because of the weaker heating, two identificable centers still exist at 120h when they are only ∿100 km apart. We note again that at small separation distances feedbacks between cumulus convection and the strom pair's interaction have been masked by the prescribed heating in our model.

The speeds at which the two tropical cyclones in Exp. 1 and 2 rotate around and approach each other are shown in Fig. 10. The tangential velocity of the cyclonic rotation in Exp. 1 increases from ∿3 m s^{-1} at 24-36h to well over 6 m s^{-1} after 72h as the separation between the two tropical cyclones becomes small. The rotation speeds in Exp. 2 are about 1 m s^{-1} slower than those in Exp. 1. However, the rate of convergence seems quite independent of the combined strength as indicated by the radial velocities in Fig. 10. The faster rotations between stronger pairs are evident observationally at small separation distances (Dong and Neumann, 1982). At larger separation distances, this relationship is not clear because the observational data contains environmental influences.

Fig. 11 shows the trajectories of the two storm center in Exp. 3, in which the maximum heating rate is storm A is only half that of storm B. We see that the two storms still rotate about each other cyclonically and that they still move toward each other. However, the trajectories are asymmetric and the weaker storm A moves much faster than the stronger storm B in a way similar to that of a binary celestial system in which the two bodies have different masses. The "mass" of a vortex is perhaps best expressed as the product of its mean

angular velocity and the square of an effective radius $\bar{\omega}R^2$. We will discuss this further later. This type of interaction between storms of different intensities has been observed between Typhoons Flossie and Grace in 1950 (Liu and Wang, 1966). Instead of being stationary, the center of rotation moved within a small area defined by the lines connecting the two storm centers at different times as in Fig. 10.

Results in Exps. 1-3 demonstrate that on an f-plane with no large scale wind, interactions between two tropical cyclones cause the two storms to rotate cyclonically, to attract each other and to coalesce eventually.

In order to examine the momentum fields associated with the interaction we transform the model 500 mb wind fields in Exp. 1 onto a polar grid with respect to the center of the model domain. We now define the azimuthal mean velocity as

$$\bar{\underset{\sim}{V}} = (\bar{v}_r, \bar{v}_\theta, \bar{v}_z) = \frac{1}{2\pi}\int_0^{2\pi} (v_r, v_\theta, v_z)\, d\theta \qquad (8)$$

where v_r, v_θ, v_z are radial, tangential and vertical velocities on the polar grid, and θ is the azimuthal angle. Fig. 12 shows the mean vertical (upper), tangential (middle), and radial (lower) velocities for Exp. 1 at 24, 48, 72, and 96h. It is interesting that the mean momentum fields relative to the center of domain shown here are similar to those in weak but intensifying tropical disturbances (Hawkins and Rubsam, 1968). For example, at 24h there is a maximum mean tangential velocity of $\sim$4 m s^{-1} at r $\sim$600 km and a minimum of $\sim$-2 m s^{-1} at r $\sim$400 km, reflecting the cyclonic wind fields about the two storm centers. The maximum tangential velocity gradually increases to $\sim$16 m s^{-1} and moves toward the center to a radius $\sim$350 km at 96h. The maximum inflow also

develops from 2 m s^{-1} at r ∿600 km at 24h to ∿4 m s^{-1} at r ∿350 km at 96h. The evolution of the mean vertical velocity includes the increasing magnitude and contracting radii of maximum upward motion. The development of the mean circulation is accompanied with the pressure decrease of 10 mb at the domain midpoint from 24-96h, as discussed before.

The development of the azimuthal mean circulation can also be illustrated by comparing the kinetic energy (KE) of the mean velocity (KEM) and the KE of the eddy velocity (KEE), where

$$KEM = \int\int_{0}^{1000\ km} \tfrac{1}{2} (\bar{v}_r, \bar{v}_\theta) \cdot (\bar{v}_r, \bar{v}_\theta)\, r dr d\theta \qquad (9)$$

$$KEE = \int\int_{0}^{1000\ km} \tfrac{1}{2} (v_r', v_\theta') \cdot (v_r', v_\theta')\, r dr d\theta \qquad (10)$$

$$\text{and } (v_r', v_\theta') = (v_r, v_\theta) - (\bar{v}_r, \bar{v}_\theta) \qquad (11)$$

As shown by Fig. 13, the KEE, which can mostly be attributed to the circulations around the two centers, reaches a quasi-steady state after 36h. Meanwhile the KEM, representing the strength of the mean circulation as depicted in Fig. 10 around the center of rotation, steadily increases until the coalescence of the two tropical cyclones. The ratio KEE/KEM decreases from ∿3 at 24h to less than 1 at 96h.

These analyses suggest that a mean circulation relative to the center of rotation develops due to the interaction of two tropical cyclones. This mean

circulation includes tangential, radial and vertical components resembling those associated with tropical cyclones. It is therefore not surprising that the trajectories of the two interacting storms are similar to the trajectories in the hurricane boundary layer (e.g. Anthes 1982, Fig. 4.6). Compared with the nondivergent, barotropic experiments in Section 2, it seems that the diabatic heating in two storms plays a cruical role for the merging of the two storms.

In additional numerical experiments, the surface friction was suppressed to test the frictional effects in the interaction. Results from these experiments were nearly identical to those presented for Exps. 1-3. We also halved the coefficients for the internal dissipation. For the same given heating rates, the interactions are nearly the same except for faster rotation rates, because the model cyclones were stronger with less internal friction. Therefore, neither surface nor internal friction seem to be critical processes in the interactions.

d. Relation of Mutual Rotation Rate to Bulk Parameters of the System

The results presented so far indicate generally that the rate of the mutual cyclonic rotation depends on the strength of the binary system and the separation distance of the two interacting storms. Perhaps by relating some extent parameters through laws governing solid body rotation, a simple description of the numerical results is attainable.

We now consider the rotation of the binary storms is similar to that of a dumbbell. The equation of motion for rotation states that the torque τ acting on the binary system is equal to the product of the rotational inertia of the system I and the angular acceleration $\dot{\omega}$ with respect to the axis of rotation, i.e.

$$\tau = I\dot{\omega} \qquad (12)$$

If we let R be an effective radius of the storm and H be the scale height, the

mass of one storm can be approximated by $\rho_o \pi R^2 H$. Because the radius of the mutual rotation is about L/2, the rotational inertia

$$I \propto \rho_o \, (\bar{R}_A^2 + \bar{R}_B^2) H L^2 \qquad (13)$$

where ρ_o is a reference density and subscript A and B are pertinent for storms A and B, respectively.

The torque is equal to the cross product of a force and radius of rotation. The force involved in the interaction can be approximated by the advection, then it can be scaled by $\rho_o \, \bar{V}^2/L$, where $\bar{V}$ is the velocity of the mean circulation defined by (8). Because the mean circulation depends on the combined strength of the two interacting cyclones, therefore $\bar{V} \propto \bar{v}_A + \bar{v}_B$, where $\bar{v}_A$ and $\bar{v}_B$ are the mean wind speed within the effective radius $\bar{R}_A$ and $\bar{R}_B$, respectively. Thus, the torque is proportional to

$$\tau \propto LH \, \rho_o \, (\bar{R}_A^2 + \bar{R}_B^2) \, (\bar{v}_A + \bar{v}_B)^2 \, L^{-1} \qquad (14)$$

We note that the torque contains the dimension of the kinetic energy of the two storms, which is ultimately related to the applied heating $\dot{Q}$ in our model. Substituting (13) and (14) into (12) and dropping the over-bars, we get

$$(v_A + v_B)^2 \propto \dot{\omega} L^2 \sim f \omega L^2 \qquad (15)$$

In above, f^{-1} is selected as the time scale, so that $\dot{\omega} \sim \omega/T \sim f\omega$. For our purposes of examining numerical results of a limited domain model away from the equator where f remain nearly a constant, the selection of f^{-1} as a time scale is justifiable.

$$\omega \propto -\frac{(v_A + v_B)}{fL^2} \qquad (16)$$

Relationship (16) states simply that the rate of the mutual rotation is proportional to the combined kinetic energy of the two interacting tropical cyclone and inversly proportional to the square of the separation distance. In addition, the displacement of one storm should be inversely proportional to its size, because the radius of rotation is inversely proportional to the mass $\pi\rho_0 R^2 H$.

In applying (16) to the numerical results, the mean wind speed within the radius of the gale force wind (17 m s^{-1}) is used as v_A and v_B. Excluding data when the separation distance is smaller than the sum of two radii of the gale force, rotation rates of binary system at every 6h were compared with $(v_A + v_B)^2/fL^2$ for Exps 1,2 and 3 (Fig. 14). It is clear the (16) is a good description of the results Exp. 1-3. The rotation rates ω and quantities $(v_A + v_B)^2/fL^2$ have a correlation coefficient of 0.81. Therefore, our numerical results can to some extent be represented by surprisingly simple relationship (16).

It should be noted, however, that (16) is arrived through several simplifying assumptions. These include approximating the mutual rotation of two vortex in the atmosphere by using solid body mechanics and excluding the merging from consideration. While (16) yields good correlation, it is only an approximation of the rotation component of the interaction.

e. <u>The Effects of Variation of the Coriolis Parameter</u>

Exps. 4-7 were carried out with variable Coriolis parameter, which can produce northwestward drifts of tropical cyclones in the northern hemisphere (Adem, 1956; Anthes and Hoke, 1975; Madala and Piacsek, 1975). The velocity of the drift depends on the latitude and the cyclone's circulation. To examine the free drift of a single tropical cyclone in our model, we carried out Exp. 4. As shown by trajectory C in Fig. 15, the model tropical cyclone has an initial northward movement, but changes toward the northwest after 36h, similar to the results of Anthes and Hoke (1975). The 0-72h mean drift velocity is 1.18 m s^{-1}

toward the west and 1.37 m s^{-1} toward the north. The center at 72h is $\sim 6^{o}$ to the west and $\sim 6.5^{o}$ to the north of the initial position.

The latitudinal variation of the Coriolis parameter has a pronounced effect on the trajectories of the two interacting tropical cyclones. The trajectories of the two tropical cyclones with equal strength in Exp. 5 are shown in Fig. 15. The two storms merge much faster than Exp. 1 due to the faster northwest drift of the storm located to the south. At 87h only one large low pressure center is identifiable, while in Exp. 1, two low pressure centers still existed at 96h (Fig. 7). Instead of rotating around the + point in Fig. 8 as in Exp. 1, storm A moves toward the southeast then quickly turns toward the northeast, while storm B rapidly moves northwestward and rotates cyclonically with respect to storm A. The two storms eventually merge into one at 87h, with storm B having traveled a much larger distance from its initial position than storm A. The relative trajectories of A and B with respect to trajectory C (Exp. 4) are computed. The resultant relative trajectories (not shown) are nearly the same as those in Exp. 1 (Fig. 3), indicating that the trajectories A and B in Fig. 15 is nearly a linear combination of the trajectories in Fig. 3 and the beta drift.

Exp. 6 is to be compared with Exp. 3, where storm A is weaker than storm B. The trajectories of the storm centers in Exp. 6 (Fig. 16) again appear very different from those in Exp. 3. The stronger storm B shows more noticeable northwest drift than in Exp. 3. The weaker storm A rotates cyclonically toward the southeast at a much reduced rate and with a smaller radius, apprently due to the counteracting beta drift.

Most interesting is Exp. 7, in which storm A is stronger than storm B. From 24 to 72h, the weaker storm B moves cyclonically relative to storm A.

In the meantime storm A moves slowly toward the southwest nearly perpendicular to and away from storm B. The trajectories take a strange turn after 72h because the two storms now are close to the boundaries and start to influence each other through the east-west boundaries because of the cyclic boundary conditions there.

The distictively different behavior between Exps. 5-7 can be explained by examining schematically the vectors of forces upon each storm. We let the northwest drift be proportional to the storm's intensity and size (Rossby, 1948; Adem, 1956) and the force due to the interaction be proportional to the combined strength of the binary system but inversely proportional to the strength of individual storm as discussed in Section 3c. Figure 17 shows the vectors and the resultant directions of movements for storm A at 24h of Exps. 5-7. In Exp. 5 both the beta drift and interaction (both the rotation and convergence are counted for) are strong, the movement of the storm is mostly due south as evident in Fig. 15. In Exp. 6, the beta drift is weaker but the interaction is the strongest, the movement is nearly along the vector of the interaction. In Exp. 7, the beta effect is strong while the interaction is weak, results in a slow movement of the strom away from storm B.

4. SUMMARY

The interactions between two mesoscale cyclonic vortices in the absence of large scale winds have been investigated with a nondivergent, barotropic model and a three-dimensional model. Model results indicate that the interactions between a nondivergent barotropic vortex pair are very different from those observed between a tropical cyclone pair, and that our three-dimensional simulations agree with the observed Fujiwhara phenomenon.

Two types of vortex pairs with various initial separation distances have been tested with the nondivergent, barotropic model. No mutual attraction is found in any of the cases tested. The curvature of the mutually induced rotation depends on the radial profile of swirl winds (or vorticities) of each vortex, the speed of mutually induced motion is a function of separation —— the closer the two vortices, the faster they move. This is quite understandable, because in such a nondivergent barotropic model the two vortices can only interact by advection. These numerical experiments suggest that the observed Fujiwhara phenomenon is caused by a more complex mechanism than just vorticity advection.

Our simulations with a three-dimensional model reproduce observed Fujiwhara effects. The trajectories of simulated strong-strong, weak-weak, and weak-strong tropical cyclone pairs on a constant-f plane all consist of cyclonic rotations and mutual attractions. The rotation rate between two strong tropical cyclones is generally faster than that between a weak pair. The rate of convergence of a weak pair is not slower than that between a strong pair.

Additional analyses show that as the tropical cyclone pair start to interact, there forms a mean circulation about the center of mass of the two storms as the pressure there decreases more than can be expected by simple advective merging. The development of the mean circulation, consisting of a cyclonic tangential flow and a inward radial flow, resembles the circulation in weak but intensifying tropical disturbances. The kinetic energy of this mean circulation grows by a factor of four in 72h in one experiment, while the kinetic energy of the circulations associated with individual tropical cyclone remains relatively unchanged. It suggests that the development of a mean circulation on the vertical-radial plane relative to the center of mass of the interacting storm pairs is crucial in generating the cyclonic mutual rotation and merging.

A simple analysis points out that the displacement of one tropical cyclone interacting with another is proportional to the combined strength of the

vortex pair and inversely proportional to its own size and to the square of the separation distance. Our model results fit this description well except for cases when interacting storms become highly asymmetric about their own centers.

The latitudinal variation of the Coriolis parameter (beta effect) has a large influence on the trajectories of the interacting storm pairs. The beta effect causes a northwest shift and a faster merging of the two tropical cyclones of equal strength. The trajectories of two interacting tropical cyclones of equal strength have a northwest drift superposed on the symmetrical trajectories found on the constant-f plane. Observation studies showed that typhoon pairs sometimes drifted away from each other if there were strong shears in large scale flow (Liu and Wang, 1966; Dong and Neumann, 1982). This study indicated that differential beta drifts can also cause the two interacting tropical cyclones of different strength to diverge when the one initially located to the west is stronger.

These findings should not be accepted without caution because of several limitations of the numerical model. The model domain is perhaps too small for two tropical cyclones. In addition, the horizontal resolution of $\frac{1}{2}^{o}$ is only marginal for resolving realistically the smaller scale dynamics near the center. Being a uniform grid model, without decreasing the horizontal resolution, the model domain cannot be expanded due to limited computing resources. The cyclic boundary conditions created problems (as evident in Exp. 7) when two storms may have interacted with each other through the east-west boundaries. Perhaps the most serious limitation of our simulation is the heating prescribed a prior in the three-dimensional simulations, which may have masked the interactions between two adjacent tropical cyclones on the scale of cumulus convections. However, the development of the mean circulation about the center of mass of the two tropical

cyclones occurs at very early stage of the interaction when the separation is still large. This suggests that the detailed characteristics of cumulus convection in individual storm may not be important in setting up the cyclic rotation and mutual attraction. The use of the prescribed heating was justifiable except at small separations where the divergent-convergent pattern in each storm may be modified due to the proximity of another one.

In future research, a parameterized convective heating should be utilized to investigate the abovementioned secondary effect of the cumulus convection. In addition, the parameterized heating may react to large scale winds in a nonlinear fashion. Therefore, the nonlinear effects of the large scale winds on the interactions of two tropical cyclones also ought to be studied. The question of what is the maximum separation distance for storm pair to interact is also left for future studies when numerical models of tropical cyclone cover a larger domain are constructed.

ACKNOWLEDGEMENTS

I thank Dr. Rangarao V. Madala for discussions and his help in utilizing his stabilized-error-vector-propagation solver program, and Dr. Darrell F. Strobel for reading and commenting on the manuscript. Dr. Richard A. Anthes critically reviewed an earlier version of the manuscript, Mr. Charles J. Neumann kindly provided me his unpublished paper (Dong and Neumann, 1982) and a copy of Fujiwhara (1931) paper. Ms. Shoba Yalamanchili typed the manuscript.

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FIGURES

Figure 1: Surface isobaric analyses at ooooZ on Sept. 15-20, 1964 showing the rotation and merging of typhoons Kathy (K) and Marie (M). Isobars are plotted every 3 mb. (From Liu and Wang, 1966).

Figure 2: The radial distribution of relative vorticity for type A (solid) and type B vortex (dashed).

Figure 3: The trajectories of type A (solid lines) and type B (dashed lines) vortices at separation distances of 300, 400, 600, and 1000 km. The cross is the center of the domain. Time interval between two adjacent dots is 12h. Squares denote the initial vortex centers.

Figure 4: The vertical distribution of heating used in the model plotted on an arbitrary scale (solid), as compared with (T_c-T) for mean hurricane sounding produced by a one-dimensional cloud model (Anthes, 1977, Fig. 4).

Figure 5: The horizontal distribution of heating used in the model plotted on an arbitrary scale (solid), as compared with the observed radial distribution of rainfall rate in a typhoon (Adler and Rodgers, 1977, Fig. 5).

Figure 6: The radial distribution of the quasi-steady wind speeds in model layer six ($\bar{\sigma} = 0.85$) and seven ($\bar{\sigma} = 0.963$) generated by the stationary prescribed heating.

Figure 7: The surface pressure field at 24, 48, 72, 84, and 96h. Contour intervals are 4 mb, the outmost closed isobars are 1008 mb. Longtitudes are arbitrarily set.

Figure 8: The trajectories of storm centers in Exp. 1. Numbers on the curve denote times in hour.

Figure 9: As in Figure 8, except for Exp. 2.

Figure 10: The tangential and radial speeds of the two interacting tropical cyclones relative to their centers of mass in Exps. 1 and 2.

Figure 11: As in Fig. 8, except for Exp. 3.

Figure 12: The azimuthal mean radial (v_r), tangential (v_θ), and vertical velocity (w) of the wind fields relatives to the center of mass in Exp. 1 at 24, 48, 72 and 96h.

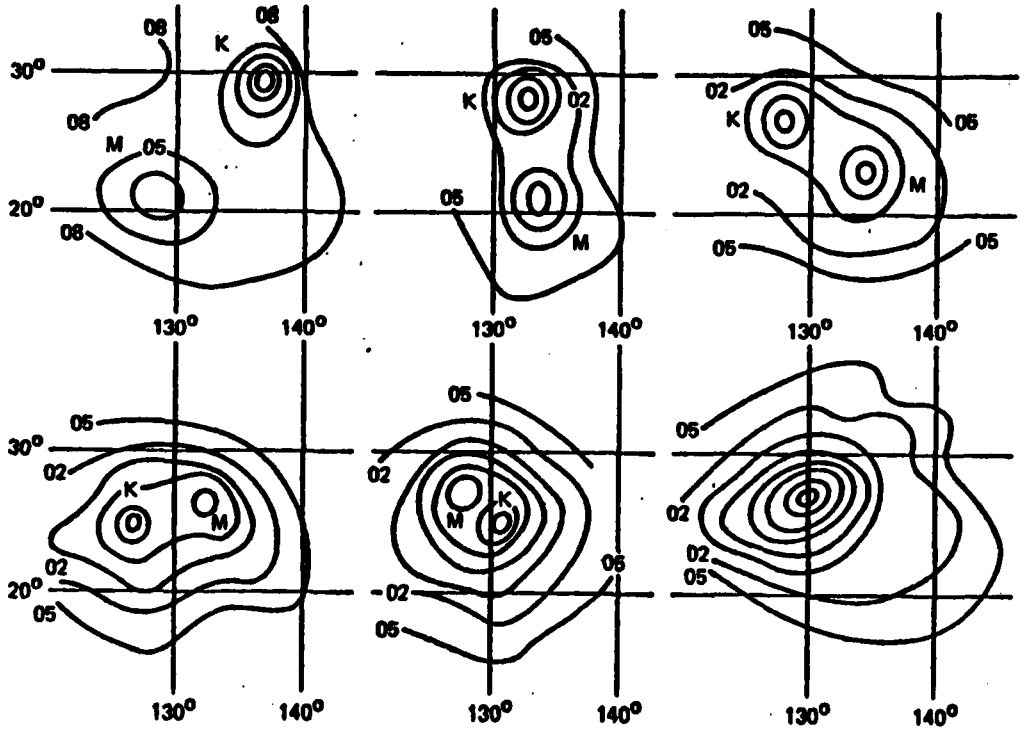
Figure 13: The development of the kinetic energy of the "mean" flow (solid) relative to the center of mass and the kinetic energy of the "eddy" associated with the two storm centers (dashed) in Exp. 1.

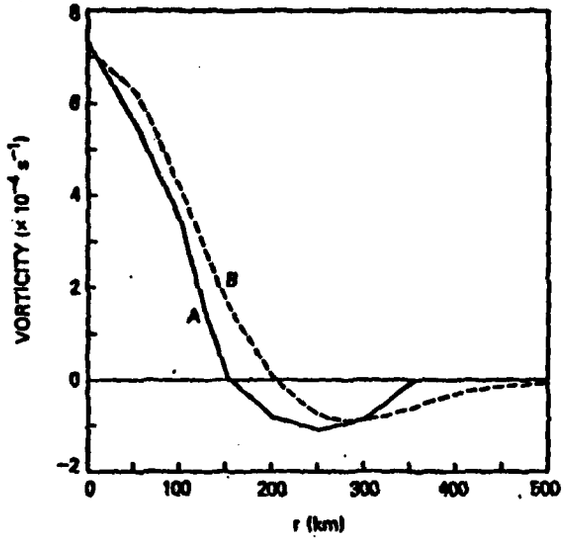
Figure 14: The rotational rates ω compared with $(v_A + v_B)^2/fL^2$.

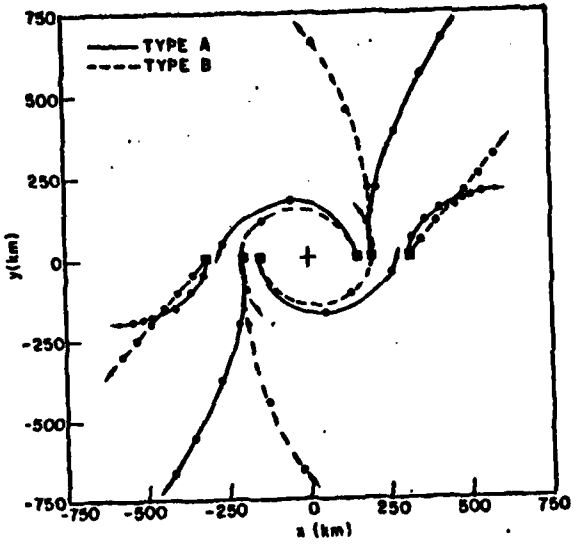
Figure 15: The trajectories of the free drifting storm in Exp. 4 (Curve C) and of the two interacting storms in Exp. 5 (Curves a and B).

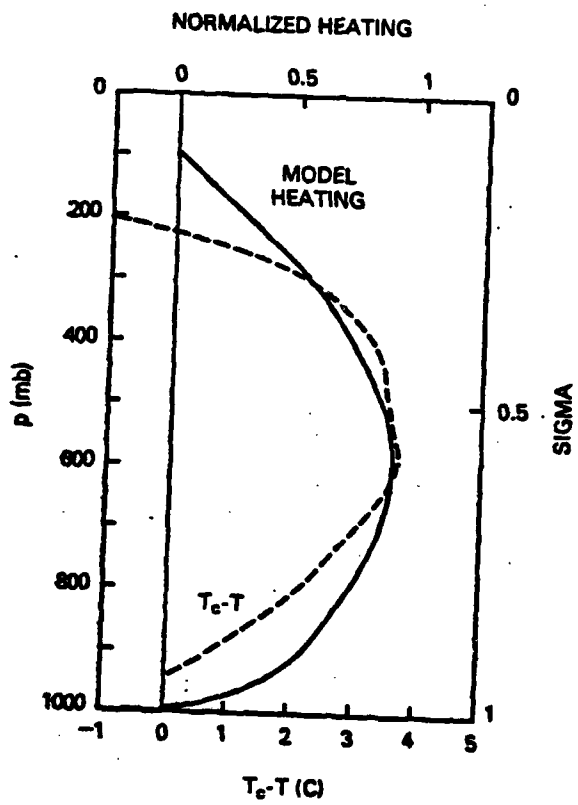
Figure 16: As in Fig. 15 except for Exps. 6 (solid lines with dots) and 7 (solid lines with squares).

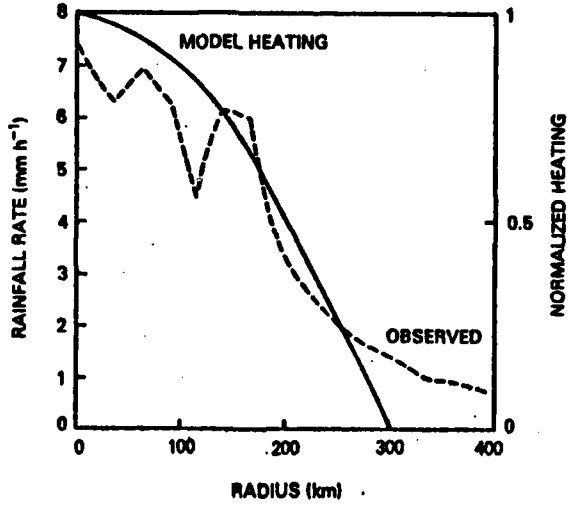
Figure 17: Vectors showing schematically the force of interaction (I), beta drift (D), and the resultant movement (M) for tropical cyclones A at 24h of Exps. 5, 6, and 7.

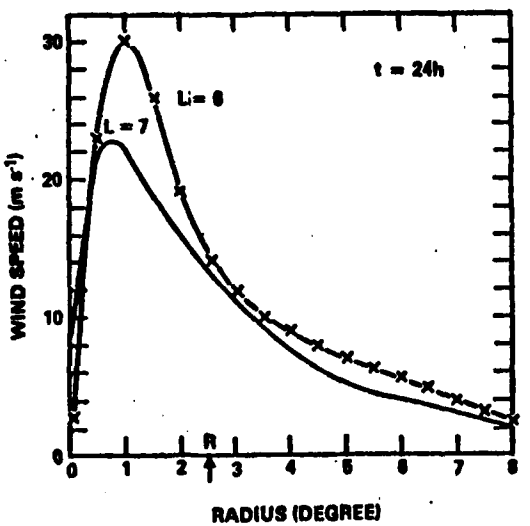

30°
20°
130°
140°
K
M
08
06
05
02

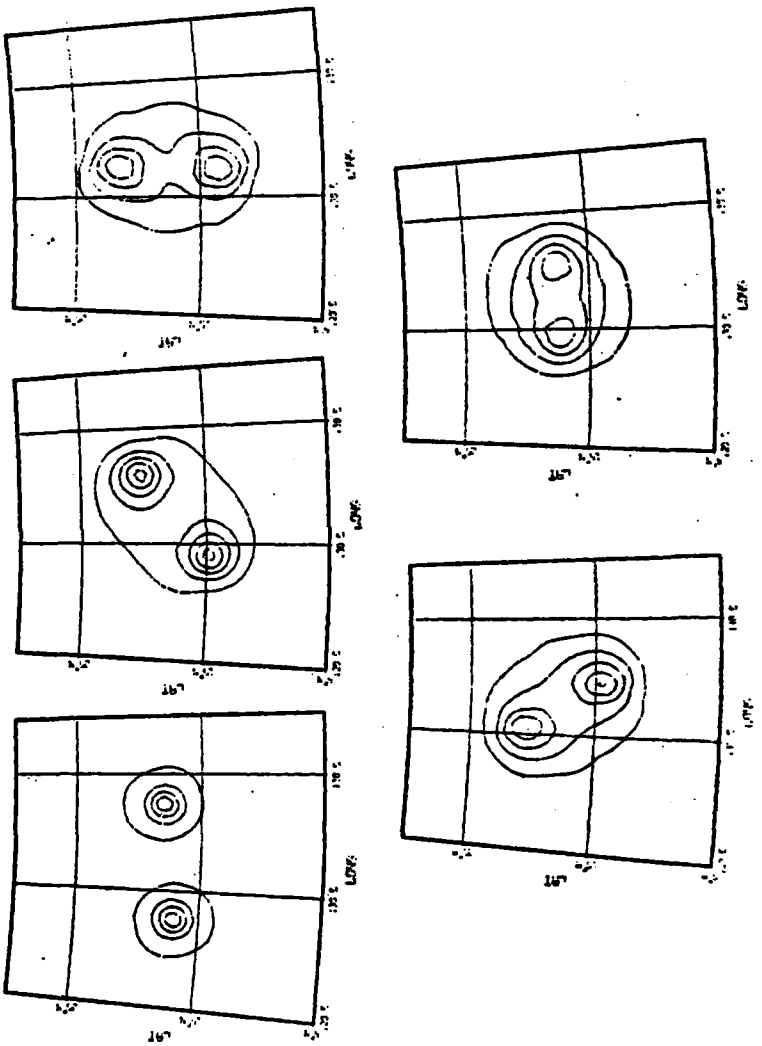

VORTICITY (× 10⁻⁴ s⁻¹)
8
6
4
2
0
−2
A
B
0
100
200
300
400
500
r (km)

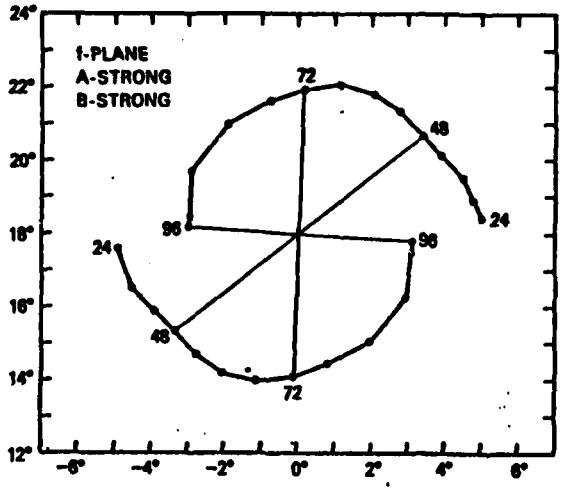

TYPE A
TYPE B
750
500
250
0
-250
-500
-750
y(km)
-750
-500
-250
0
250
500
750
x (km)

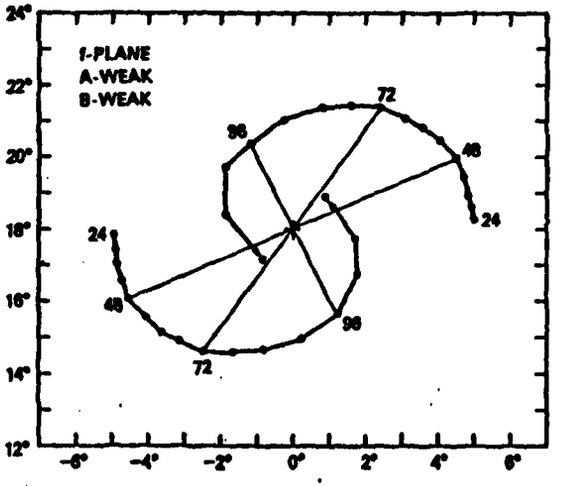

NORMALIZED HEATING
0
0
0.5
1
0
MODEL
HEATING
200
400
600
800
1000
p (mb)
0.5
SIGMA
T_c-T
−1
0
1
2
3
4
5
1
T_c-T (C)

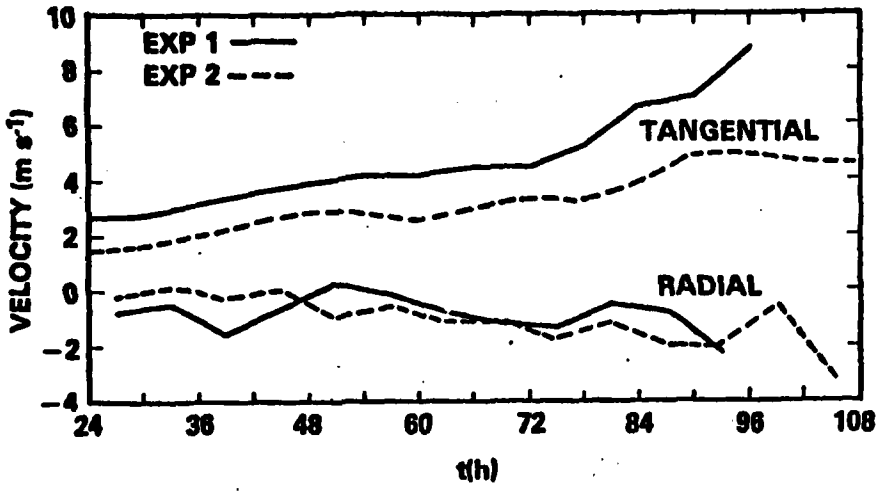

MODEL HEATING
OBSERVED
RAINFALL RATE (mm h⁻¹)
NORMALIZED HEATING
RADIUS (km)
0
1
2
3
4
5
6
7
8
0.5
100
200
300
400

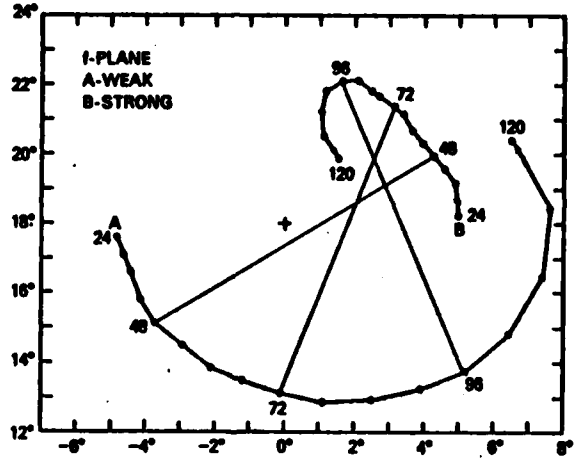

t = 24h
Li= 6
L = 7
WIND SPEED (m s⁻¹)
30
20
10
0
R
0 1 2 3 4 5 6 7 8
RADIUS (DEGREE)

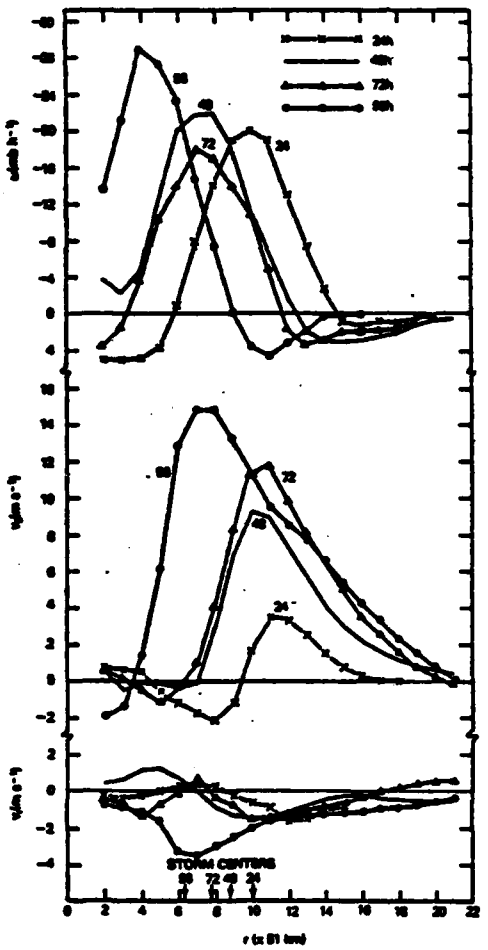


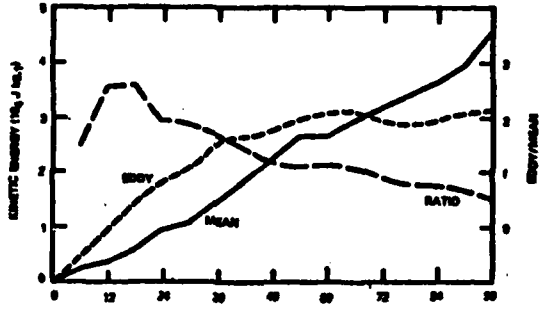

1-PLANE
A-STRONG
B-STRONG
24°
22°
20°
18°
16°
14°
12°
-6°
-4°
-2°
0°
2°
4°
6°
72
48
24
96
96
24
48
72

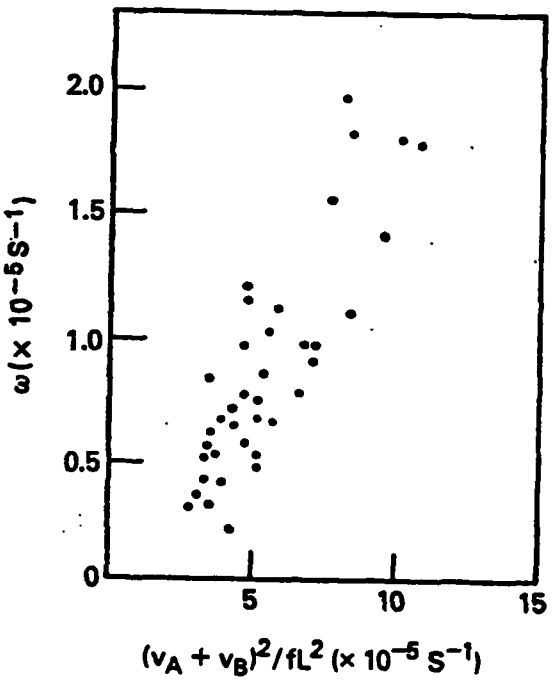

f-PLANE
A-WEAK
B-WEAK
24°
22°
20°
18°
16°
14°
12°
-6°
-4°
-2°
0°
2°
4°
6°
72
96
48
24
24
48
96
72

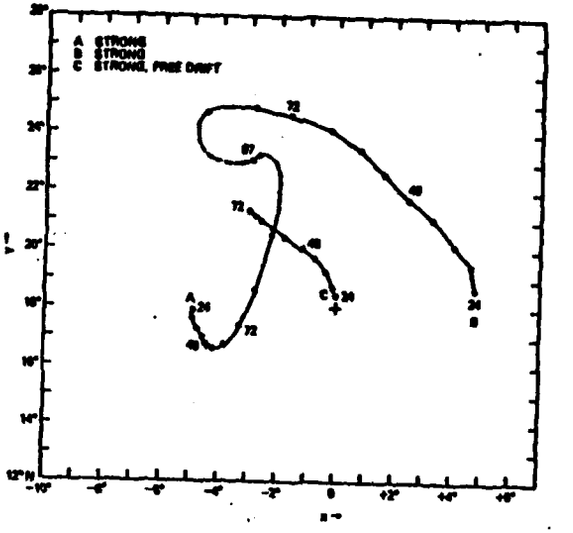

EXP 1
EXP 2
TANGENTIAL
RADIAL
VELOCITY (m s⁻¹)
10
8
6
4
2
0
−2
−4
24
36
48
60
72
84
96
108
t(h)

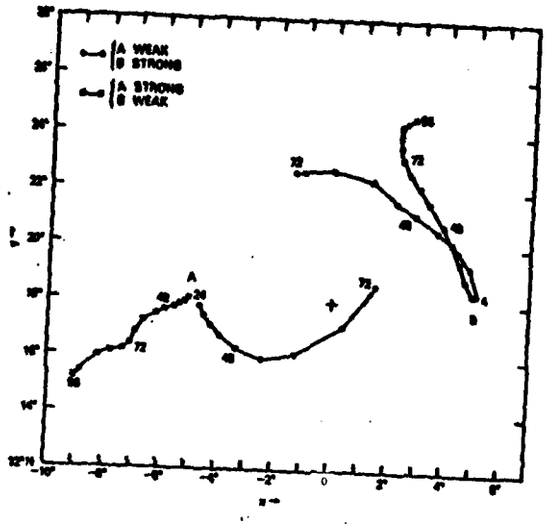

I-PLANE
A-WEAK
B-STRONG
24°
22°
20°
18°
16°
14°
12°
-6°
-4°
-2°
0°
2°
4°
6°
8°
96
72
48
120
120
A
24
B
24
48
72
96

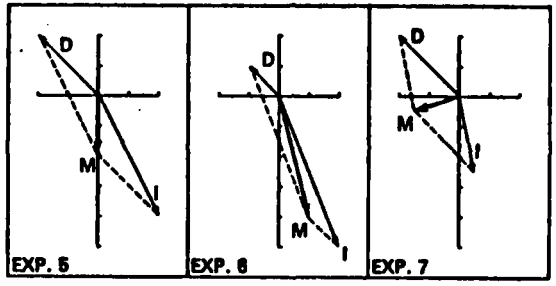

STORM CENTERS
96 72 48 24
0 2 4 6 8 10 12 14 16 18 20 22


ERDV
MEAN
RATIO


2.0
1.5
1.0
0.5
0
5
10
15
ω(× 10⁻⁵S⁻¹)
(v_A + v_B)²/fL² (× 10⁻⁵ S⁻¹)


A STRONG
B STRONG
C STRONG, FREE DRIFT


A WEAK
B STRONG
A STRONG
B WEAK
A
B


D
M
I
EXP. 5
D
M
I
EXP. 6
D
M
I
EXP. 7

APPENDIX II

AN AXISYMMETRIC MODEL FOR A NON-HYDROSTATIC BOUSSINESQ OCEAN

AN AXISYMMETRIC MODEL FOR A NON-HYDROSTATIC BOUSSINESQ OCEAN

Simon Wei-Jen Chang
Science Applications, Inc.
McLean, VA 22102

January 1983

CONTENTS

AN AXISYMMETRIC, NUMERICAL MODEL FOR A NON-HYDROSTATIC BOUSSINESQ OCEAN

1. GOVERNING EQUATIONS

The governing equations of the axisymmetric, non-hydrostatic, Boussinesq ocean model are

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial r} + w\frac{\partial u}{\partial z} = \frac{v^2}{r} + fv - \frac{1}{\rho_o}\frac{\partial p}{\partial r} + K_H\left(\nabla^2 u - \frac{u}{r^2}\right) + K_z\frac{\partial^2 u}{\partial z^2} \tag{1-1}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial r} + w\frac{\partial v}{\partial z} = -\frac{uv}{r} - fu + K_H\left(\nabla^2 v - \frac{v}{r^2}\right) + K_z\frac{\partial^2 v}{\partial z^2} \tag{1-2}$$

$$\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial r} + w\frac{\partial w}{\partial z} = -b - \frac{1}{\rho_o}\frac{\partial p}{\partial z} + K_H\nabla^2 w + K_z\frac{\partial^2 w}{\partial z^2} \tag{1-3}$$

$$\frac{\partial b}{\partial t} + u\frac{\partial b}{\partial r} + w\frac{\partial b}{\partial z} = N_z^2 w + K_H\nabla^2 b + K_z\frac{\partial^2 b}{\partial z^2} \tag{1-4}$$

where $\nabla^2 \equiv \frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r}$, other symbols are listed in Appendix A. Above, the density anomaly b is defined according to

$$b = \frac{\rho - \rho_r(z)}{\rho_o} g \ , \tag{1-5}$$

where $\rho_r(z)$ is a reference density and is a function of depth only. Brunt-Väisällä frequency N_z is defined as

$$N_z = \sqrt{\left(\frac{-g}{\rho_o}\frac{\partial \rho_r}{\partial z}\right)} \tag{1-6}$$

Manuscript approved September 29, 1982.

The continuity equation is that of the incompressible fluid,

$$\frac{1}{r}\frac{\partial ur}{\partial r} + \frac{\partial w}{\partial z} = 0 \qquad (1-7)$$

2. THE MODEL GRID

It is determined that a fully staggered grid is most expedient for storage economy for a given spatial resolution. As shown in Fig. 1, the radial (u) and the tangential (v) velocities are defined at cross points, vertical velocities (w) are defined at open circle points, and the pressures (p) and density anomalies (b) are defined at blackened dot points. This grid system has the following advantages:

a) it saves storage for a given spatial resolution

b) it is very economical in terms of number of computational operations for the finite difference (FD) equations of (1-1) to (1-4).

c) it is very easy to specify the boundary conditions,

d) the pressure diagnostic equation, of the elliptic type, can be reduced to the standard form, and

e) there is no spatial separation of solutions on the grid.

In order to consistently index the grid points, we let index pair (ij) represent the i-th point in the r-direction and j-th point in the z-direction. In addition, m is the maximum number of points in the r-direction, and n, the maximum number of points in the z-direction. Therefore there are m x (n-1) points for radial and tangential velocities, (m-1) x n points for vertical velocities, and (m-1) x (n-1) points for mass distribution (b and p').

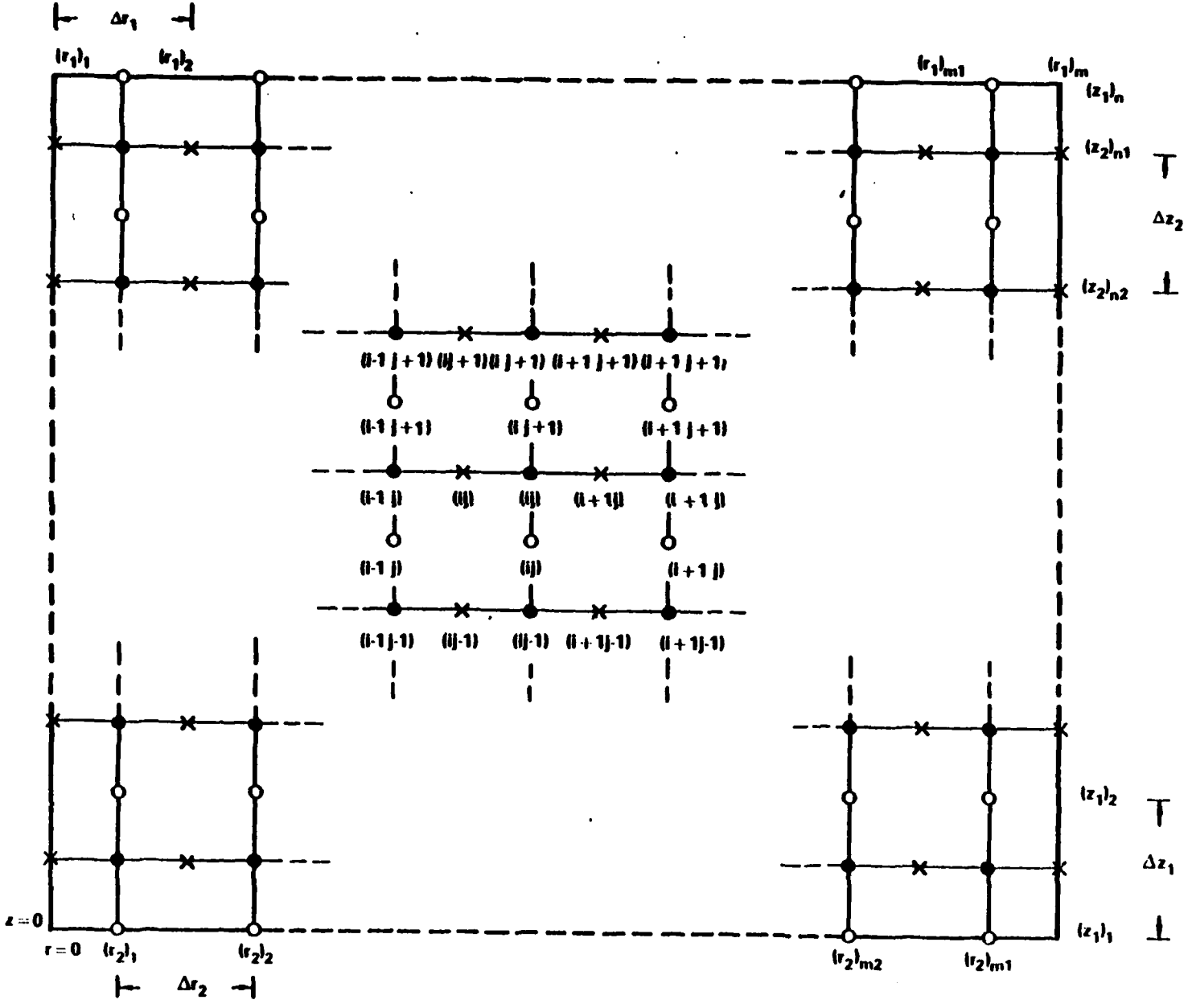


Fig. 1 The fully staggered grid system of the ocean model.

3. THE FINITE DIFFERENCE EQUATIONS

The leapfrog, or centered-in-time, integration scheme for the inviscid terms and the forward-in-time integration scheme for the viscous terms are used. The scheme is described as

$$\begin{Bmatrix} u^{t+\Delta t} \\ v^{t+\Delta t} \\ w^{t+\Delta t} \\ b^{t+\Delta t} \end{Bmatrix} = \begin{Bmatrix} u^{t-\Delta t} \\ v^{t-\Delta t} \\ w^{t-\Delta t} \\ b^{t-\Delta t} \end{Bmatrix} + 2\Delta t \begin{Bmatrix} \frac{\partial u}{\partial t}^t \\ \frac{\partial v}{\partial t}^t \\ \frac{\partial w}{\partial t}^t \\ \frac{\partial b}{\partial t}^t \end{Bmatrix} \qquad (3\text{-}1)$$

A second order, or centered-in-space, scheme is applied to derive the tendencies in (3-1) according to (1-1) ~ (1-4).

(a) <u>The Equation of Motion in r-direction</u>

$$\frac{\partial u^t_{ij}}{\partial t} = H^t_{ij} - \frac{1}{\rho_o} \frac{1}{(\Delta r_2)_i} (p_{ij} - p_{i-ij}) \qquad (3\text{-}2)$$

where

$$H_{ij}^{t} = -0.25 \left[\frac{1}{(\Delta r_1)_{i-1}} (u_{ij}^{t}+u_{i-1j}^{t})(u_{ij}^{t}-u_{i-1j}^{t}) \right.$$

$$+ \frac{1}{(\Delta r_1)_{i}} (u_{i-1j}^{t}+u_{ij}^{t})(u_{i+1j}^{t}-u_{ij}^{t})$$

$$+ \frac{1}{(\Delta z_2)_{j}} (w_{i-1j}^{t}+w_{ij}^{t})(u_{ij}^{t}-u_{ij-1}^{t})$$

$$\left. + \frac{1}{(\Delta z_2)_{j+1}} (w_{ij+1}^{t}+w_{i-1j+1}^{t})(u_{ij+1}^{t}-u_{ij}^{t}) \right]$$

$$+ v_{ij}^{t} \left[\frac{v_{ij}^{t}}{(r_1)_{i}} + f \right]$$

$$+ K_H \left\{ \frac{1}{(\Delta r_2)_{i}} \left[\frac{1}{(\Delta r_1)_{i}} (u_{i+1j}^{t-\Delta t}-u_{ij}^{t-\Delta t}) \right. \right.$$

$$\left. - \frac{1}{(\Delta r_1)_{i-1}} (u_{ij}^{t-\Delta t}-u_{i-1j}^{t-\Delta t}) \right]$$

$$+ 0.5 \left[\frac{1}{(r_2)_{i}(\Delta r_1)_{i}} (u_{i+1j}^{t-\Delta t}-u_{ij}^{t-\Delta t}) \right.$$

$$\left. + \frac{1}{(r_2)_{i-1}(\Delta r_1)_{i-1}} (u_{ij}^{t-\Delta t}-u_{i-1j}^{t-\Delta t}) \right]$$

$$\left. - \frac{u_{ij}^{t-\Delta t}}{(r_1)_{i}^{2}} \right\} + \frac{K_z}{(\Delta z_1)_{j}} \left[\frac{1}{(\Delta z_2)_{j-1}} (u_{ij-1}^{t-\Delta t}-u_{ij}^{t-\Delta t}) \right.$$

$$\left. - \frac{1}{(\Delta z_2)_{j}} (u_{ij}^{t-\Delta t}-u_{ij-1}^{t-\Delta t}) \right] \qquad 3-3$$

(b) The Equation of Motion in θ-direction

$$\frac{\partial v_{ij}^t}{\partial t} = -0.25 \left[\frac{1}{(\Delta r_1)_{i-1}} (u_{ij}^t + u_{i-1j}^t)(v_{ij}^t - v_{i-1j}^t) \right.$$

$$+ \frac{1}{(\Delta r_1)_i} (u_{i+1j}^t + u_{ij}^t)(v_{i+1j}^t - v_{ij}^t)$$

$$+ \frac{1}{(\Delta z_2)_j} (w_{i-1j}^t + w_{ij}^t)(v_{ij}^t - v_{ij-1}^t)$$

$$\left. + \frac{1}{(\Delta z_2)_{j+1}} (w_{ij+1}^t + w_{i-1j+1}^t)(v_{ij+1}^t - v_{ij}^t) \right]$$

$$- u_{ij}^t \left[\frac{v_{ij}^t}{(r_1)_i} + f \right]$$

$$+ \frac{K_H}{(\Delta r_2)_i} \left\{ \left[\frac{1}{(\Delta r_1)_i} (v_{i+1j}^{t-\Delta t} - v_{ij}^{t-\Delta t}) \right. \right.$$

$$\left. - \frac{1}{(\Delta r_1)_{i-1}} (v_{ij}^{t-\Delta t} - v_{i-1j}^{t-\Delta t}) \right]$$

$$+ 0.5 \left[\frac{1}{(r_2)_i (\Delta r_1)_i} (v_{i+1j}^{t-\Delta t} - v_{ij}^{t-\Delta t}) \right.$$

$$\left. \left. + \frac{1}{(r_2)_{i-1} (\Delta r_1)_{i-1}} (v_{ij}^{t-\Delta t} - v_{i-1j}^{t-\Delta t}) \right] \right.$$

$$\left. - \frac{v_{ij}^{t-\Delta t}}{(r_1)_i^2} \right\} + \frac{K_z}{(\Delta z_1)_j} \left[\frac{1}{(\Delta z_2)_{j-1}} (v_{ij-1}^{t-\Delta t} - v_{ij}^{t-\Delta t}) \right.$$

$$\left. - \frac{1}{(\Delta z_2)_j} (v_{ij}^{t-\Delta t} - v_{ij-1}^{t-\Delta t}) \right] \qquad 3-4)$$

(c) The Equation of Motion in z-direction

$$\frac{\partial w_{ij}^t}{\partial t} = G_{ij}^t - \frac{1}{\rho_o(\Delta z_2)_j}(P_{ij}-P_{ij-1}) \qquad (3-5$$

where

$$G_{ij}^t = -0.25\left[\frac{1}{(\Delta r_2)_i}(u_{ij}^t+u_{ij-1}^t)(w_{ij}^t-w_{i-1j}^t)\right.$$

$$+\frac{1}{(\Delta r_2)_{i+1}}(u_{i+1j}^t+u_{i+1j-1}^t)(w_{i+1j}^t-w_{ij}^t)$$

$$+\frac{1}{(\Delta z_1)_{j-1}}(w_{ij-1}^t+w_{ij}^t)(w_{ij}^t-w_{ij-1}^t)$$

$$\left.+\frac{1}{(\Delta z_1)_j}(w_{ij+1}^t+w_{ij}^t)(w_{ij+1}^t-w_{ij}^t)\right]$$

$$-0.5(b_{ij}^t+b_{ij-1}^t)$$

$$+K_H\left\{\frac{1}{(\Delta r_1)_i}\left[\frac{1}{(\Delta r_2)_{i+1}}(w_{i+1j}^{t-\Delta t}-w_{ij}^{t-\Delta t})\right.\right.$$

$$\left.-\frac{1}{(\Delta r_2)_i}(w_{ij}^{t-\Delta t}-w_{i-1j}^{t-\Delta t})\right]$$

$$+0.5\left[\frac{1}{(r_1)_{i+1}(\Delta r_2)_{i+1}}(w_{i+1j}^{t-\Delta t}-w_{ij}^{t-\Delta t})\right.$$

$$\left.\left.+\frac{1}{(r_1)_i(\Delta r_2)_i}(w_{ij}^{t-\Delta t}-w_{i-1j}^{t-\Delta t})\right]\right\}$$

$$+ \frac{K_z}{(\Delta z_2)_j}\left[\frac{1}{(\Delta z_1)_j}(w_{ij+1}^{t-\Delta t}-w_{ij}^{t-\Delta t}) - \frac{1}{(\Delta z_1)_{j-1}}(w_{ij}^{t-\Delta t}-w_{ij-1}^{t-\Delta t})\right] \quad (3\text{-}6)$$

(d) The Thermodynamic Equation

$$\frac{\partial b_{ij}^t}{\partial t} = -0.5\left[\frac{u_{ij}^t}{(\Delta r_2)_i}(b_{ij}^t-b_{i-1j}^t) + \frac{u_{i+1j}^t}{(\Delta r_2)_{i+1}}(b_{i+1j}^t-b_{ij}^t)\right.$$

$$\left. + \frac{w_{ij}^t}{(\Delta z_2)_j}(b_{ij}^t-b_{ij-1}^t) + \frac{w_{ij+1}}{(\Delta z_2)_{j+1}}(b_{ij+1}^t-b_{ij}^t)\right]$$

$$+ 0.5\ (w_{ij+1}^t+w_{ij}^t)\ N_z^2$$

$$+ K_H\left\{\frac{1}{(\Delta r_1)_i}\left[\frac{1}{(\Delta r_2)_{i+1}}(b_{i+1j}^{t-\Delta t}-b_{ij}^{t-\Delta t})\right.\right.$$

$$\left. - \frac{1}{(\Delta r_2)_i}(b_{ij}^{t-\Delta t}-b_{i-1j}^{t-\Delta t})\right]$$

$$+ 0.5\left[\frac{1}{(r_1)_{i+1}(\Delta r_2)_{i+1}}(b_{i+1j}^{t-\Delta t}-b_{ij}^{t-\Delta t})\right.$$

$$\left.\left. + \frac{1}{(r_1)_i(\Delta r_2)_i}(b_{ij}^{t-\Delta t}-b_{i-1j}^{t-\Delta t})\right]\right\}$$

$$+ \frac{K_z}{(\Delta z_1)_j}\left[\frac{1}{(\Delta z_2)_{j+1}}(b_{ij+1}^{t-\Delta t}-b_{ij}^{t-\Delta t})\right.$$

$$\left. - \frac{1}{(\Delta z_2)_j}(b_{ij}^{t-\Delta t}-b_{ij-1}^{t-\Delta t})\right] \quad (3\text{-}7)$$

4. DERIVATION OF THE DIAGNOSTIC EQUATION FOR PRESSURE

The nonhydrostatic pressure at time t is needed to compute the pressure gradient forces in (3-2) and (3-5). To "recover" the pressure from the motion fields, we make use of the continuity equation by differentiating (1-7) with time we get

$$\frac{1}{r}\frac{\partial}{\partial r} r \frac{\partial u}{\partial t} + \frac{\partial}{\partial z}\frac{\partial w}{\partial t} = 0 ,$$

which can be written in finite difference form for a mass point ij as

$$\frac{1}{\frac{1}{2}\left[(r_1)_i + (r_1)_{i+1}\right](\Delta r_1)_i}\left[(r_1)_{i+1}\frac{\partial u^t_{i+1j}}{\partial t} - (r_1)_i \frac{\partial u^t_{ij}}{\partial t}\right]$$

$$+ \frac{1}{(\Delta z_1)_j}\left[\frac{\partial w^t_{ij+1}}{\partial t} - \frac{\partial w^t_{ij}}{\partial t}\right] = 0 \qquad (4\text{-}1)$$

Let $$c_i = (r_1)_{i+1} \Big/ \left\{\frac{1}{2}\left[(r_1)_i + (r_1)_{i+1}\right](\Delta r_1)_i\right\}, \qquad (4\text{-}2)$$

and $$a_i = (r_1)_i \Big/ \left\{\frac{1}{2}\left[(r_1)_i + (r_1)_{i+1}\right](\Delta r_1)_i\right\}$$

Substituting (3-2), (3-5) and (4-2) into (4-1), we have

$$c_i H^t_{i+1j} - \frac{1}{\rho_o}\frac{c_i}{(\Delta r_2)_{i+1}}(p_{i+1j}-p_{ij}) - a_i H^t_{ij}$$

$$+ \frac{1}{\rho_o}\frac{a_i}{(\Delta r_2)_i}(p_{ij}-p_{i-1j}) + \frac{1}{(\Delta z_1)_j} G^t_{ij-1} - \frac{1}{(\Delta z_1)_j} G^t_{ij}$$

$$- \frac{1}{\rho_o(\Delta z_1)_j(\Delta z_2)_{j+1}}(p_{ij+1} - p_{ij})$$

$$+ \frac{1}{\rho_o(\Delta z_1)_j(\Delta z_2)_j}(p_{ij}-p_{ij-1}) = 0$$

After some rearrangements, we get

$$- \frac{c_i}{(\Delta r_2)_{i+1}} p_{i+1j} - \frac{a_i}{(\Delta r_2)_i} p_{i-1j}$$

$$- \frac{1}{(\Delta z_1)_j(\Delta z_2)_j} p_{ij-1} - \frac{1}{(\Delta z_1)_j(\Delta z_2)_{j+1}} p_{ij+1}$$

$$+ \left[\frac{c_i}{(\Delta r_2)_{i+1}} + \frac{a_i}{(\Delta r_2)_i} + \frac{1}{(\Delta z_1)_j(\Delta z_2)_{j+1}} + \frac{1}{(\Delta z_1)_j(\Delta z_2)_j}\right] p_{ij}$$

$$= \rho_o\left[- c_i H^t_{i+1j} + a_i H^t_{ij} - \frac{1}{(\Delta z_1)_j} G^t_{ij+1} + \frac{1}{(\Delta z_1)_j} G^t_{ij}\right] \quad (4-3)$$

Now let $-F_{ij}$ = RHS of (4-3),

$$CX_i = \frac{c_i}{(\Delta r_2)_{i+1}} = (r_1)_{i+1} \left\{ \frac{1}{2} \left[(r_1)_i - (r_1)_{i+1} \right] \right.$$

$$\left. (\Delta r_1)_i (\Delta r_2)_{i+1} \right\} ,$$

$$AX_i = \frac{a_1}{(\Delta r_2)_i} = (r_1)_i \left\{ \frac{1}{2} \left[(r_1)_i - (r_1)_{i-1} \right] \right.$$

$$\left. (\Delta r_1)_i (\Delta r_2)_i \right\} ,$$

$$CZ_j = 1/\left[(\Delta z_1)_j (\Delta z_2)_{j+1} \right] ,$$

$$AZ_j = 1/\left[(\Delta z_1)_j (\Delta z_2)_j \right] , \text{ and}$$

$$BB_{ij} = - CX_i - AX_i - CZ_j - AZ_j \qquad (4-4)$$

We obtain the standard form of an elliptic equation in FD form

$$AX_i P_{i-1j} + AZ_j P_{ij-1} + BB_{ij} P_{ij} + CX_i P_{i+1j} + CZ_j P_{ij+1} = F_{ij} \qquad (4-5)$$

Equation (4-5) can be solved numerically by the SEVP solver (Madala, 1978), providing the boundary conditions are properly posed.

The conditions for the four boundaries are determined according to the following assumptions:

(a) At $(r_1)_i = (r_1)_1 = 0$, the natural condition for the cylindrical coordinates calls for $u = v = 0 = \partial u/\partial t = \partial v/\partial t$, the gradient balance requires that $(\partial P/\partial r)_{r=0} = 0$. Therefore an extra column of P is needed

$$P_{oj} = P_{1j} \qquad (4-6)$$

(b) At $(r_1)_i = (r_1)_m$, assuming both the horizontal divergence and the vorticity are continuous, i.e., $\frac{\partial}{\partial r}\frac{1}{r}\frac{\partial ur}{\partial r} = 0$ and $\frac{\partial}{\partial r}\frac{1}{r}\frac{\partial vr}{\partial r} = 0$. These lead to

$$u_{mj} = b_a u_{m1j} + b_b[(r_1)_{m1}u_{m1j} - (r_1)_{m2}u_{m2j}]$$
$$v_{mj} = b_a v_{m1j} + b_b[(r_1)_{m1}v_{m1j} - (r_1)_{m2}v_{m2j}] \qquad (4\text{-}7)$$

where $b_a = (r_1)_{m1}/(r_1)_m$, and

$$b_b = [(r_1)_{m1}+(r_1)_m](\Delta r_1)_{m1}/\left\{(\Delta r_1)_{m2}[(r_1)_{m1}+(r_1)_{m2}]\right\}$$

Note that if b_b is set equal to zero, (4-7) describes a non-divergent and zero-vorticity boundary condition at $r = (r_1)_m$. Once v_{mj} is determined, a gradient balance at $r = (r_1)_m$ requires

$$\rho_o v_{mj}\left[\frac{v_{mj}}{(r_1)_m} + f\right] = \frac{1}{(\Delta r_2)_m}(p_{mj}-p_{m-1j})$$

or

$$p_{mj} = p_{m-1j} + \rho_o(\Delta r_2)_m v_{mj}\left[\frac{v_{mj}}{(r_1)_m} + f\right] \qquad (4\text{-}8)$$

where a column of dummy points p_{mj} has been introduced for computational purposes. The second part of the RHS of (4-8) is thus the forcing function at $r_1)_m$ for the elliptic equation (4-5).

(c) At the bottom, $w_{i1} = \frac{\partial}{\partial t} w_{i1} = 0$. Substituting these into the continuity equation (4-1), we get

$$\frac{1}{\frac{1}{2}(r_1)_i + (r_i)_{i-1}(\Delta r_1)_i}\left[(r_1)_{i+1}\frac{\partial u^t_{i+1,1}}{\partial t} - (r_1)_i \frac{\partial u^t_{i1}}{\partial t}\right]$$

$$+ \frac{1}{(\Delta z_1)_1}\frac{\partial w^t_{i2}}{\partial t} = 0 \ . \qquad (4\text{-}9)$$

Following the same deduction between (4-1) and (4-5), we get an expression similar to (4-5) with the second team on the LHS and G_{i1} in the RHS absent. Thus, P_{i1} can be obtained by the same SEVP solver by setting $C\Sigma_1 = 0$ and $G_{i1} = 0$.

(d) At top $w_{in} = \partial/\partial t\ w_{in} = 0$. Following the same line of reasoning as in (c), we obtain P_{in} by solving (4-5) with $C\Sigma_n\ P_{in+1} = 0$ and $G_{in} = 0$.

In summary, the elliptic pressure diagnostic equation (4-4) is to be solved with the following boundary conditions

1) At $r = 0$ $\quad P_{oj} = P_{1j}$ $\quad$ i.e., (4-6)

2) At $r = (r_1)_m$ $\quad P_{mj} = P_{m-1j} +$ function (v_{mj}) (4-8)

3) At $z = 0$ $\quad A\Sigma_1 = 0$ $\quad$ and $\quad G_{i1} = 0$

4) At $z = (z_1)_n$ $\quad C\Sigma_n = 0$ $\quad$ and $\quad G_{in} = 0$

LIST OF SYMBOLS

AX_i	an array of constants, varying only in r-direction, defined by (4-4), used in (4-5)
AZ_j	an array of constants, varying only in z-direction defined by (4-4), used in (4-5)
a_i	an array of constants related to r_1 and Δr_1 used in (4-2)
BB_{ij}	an array of constants, used in (4-5)
b	density anomalies, defined in (1-5), cm s^{-2}
CX_i	an array of constants, varying only in r-direction, defined by (4-4), used in (4-5)
CZ_j	an array of constants, varying only in z-direction, defined by (4-4), used in (4-5)
c_i	an array of constants, related to r_1 and Δr_1, used in (4-5)
f	Coriolis parameter, s^{-1}
g	gravitational acceleration, cm s^{-2}
i	an index, denoting i-th point in r-direction
j	an index, denoting j-th point in z-direction
K_H	horizontal diffusion coefficient, cm^2 s^{-1}
K_z	vertical diffusion coefficient, cm^2 s^{-1}
LHS	left hand side
m	the maximum number of grid points in r-direction, upper bound of i

m_1	m-1
m_2	m-2
N_2	Brunt-Väisällä frequency, s^{-1}
n	the maximum number of grid points in z-direction, upper bound of j
n_1	n-1
n_2	n-2
p	pressure, dyne cm^{-2}
RHS	right hand side
r	radius, cm
r_1	radii of momentum points, cm
r_2	radii of mass points, cm
Δr_1	distance between two horizontally adjacent momentum points, cm
Δr_2	distance between two horizontally adjacent mass points, cm
SEVP	stabilized error vector propagation
t	time, s
Δt	time interval, s
u	radial velocity, cm s^{-1}
v	tangential velocity, cm s^{-1}
w	vertical velocity, cm s^{-1}
z	height from ocean bottom, cm
z_1	heights of circle points, cm
z_2	heights of cross and dot points, cm

Δz_1 distance between two vertically adjacent circle points, cm

Δz_2 distance between two vertically adjacent cross or dot points

ρ density, g cm^{-3}

ρ_o a constant density, 1 g cm^{-3}

ρ_r a reference density, varying only in z-direction, g cm^{-3}

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REFERENCE

Madala, R. V., 1978: An Efficient Direct Solver for Separable and Non-Separable Elliptic Equations. Month Weather Review, 106, 1735-1741.

APPENDIX A — FORTRAN CODE FOR THE NON—HYDROSTATIC MODEL

A listing of FORTRAN code of the ocean model. The major functions of the main program and subroutines are as follows:

OCEAN	main program, calls all subroutines, manages job flow, controls input/output.
INIT	sets up independent variables, defines constants
START	defines initial conditions
PUTOUT	gets various fields ready for output
MAP	prints
ADVECT	computes all inviscous terms, except for the pressure gradient forces
DIFF	computes horizontal and vertical diffusions
PRESS	solves the pressure diagnostic equations and computes the pressure gradient forces, appears only in the non-hydrostatic version
MATINV	inverts matrices } Used in SEVP method
BSM1	} Used in SEVP method
BSM2	} Used in SEVP method
BSM3	} Used in SEVP method
FRWRD	matches forward
BOUNDV	sets outer boundary conditions for momentum
CHECK	checks if the time step is linearly stable.

APPENDIX B — FORTRAN CODE FOR THE HYDROSTATIC MODEL

The hydrostatic version of the model can be obtained by simplifying the non-hydrostatic version. In the hydrostatic version, the equation of motion in z-direction (1-5) is reduced to the hydrostatic equation

$$-\frac{1}{\rho_o}\frac{\partial p}{\partial z} = b \tag{B-1}$$

Instead of solving the elliptic equation (4-5), the pressure p is thus obtainable by vertically integrating (B-1). The vertical velocity w can also be computed by vertically integrating the continuity equation (1-7).

The FD forms of (B-1) and (1-7) are, respectively,

$$p_{ij} = p_{ij-1} - 0.5\ \rho_o(\Delta z_r)_j\ (B^t_{ij} + B^t_{ij-1}) \tag{B-2}$$

$$w_{ij} = w_{ij} + \frac{\left|(r_1)_{i+1}\ u^t_{i+1j-1} - (r_1)_i\ u^t_{ij-1}\right|(\Delta z_1)_j}{0.5\ (\Delta r_1)_i\ \left|(r_1)_{i+1} + (r_1)_i\right|} \tag{B-3}$$

```
CARD IMAGE FILE EDITOR(CIFEM) -- VERSION 05.29  DATE=10/26/82       TIME=14:12:12:99

<<SPLIT OCEAN0,SOLRCO,PRINT,SEC

      1*       PROGRAM OCEAN                                                  0001000
      2*       PARAMETER M=21,N=21                                            0002000
      3*       PARAMETER M1=M-1,M2=M-2,N1=N-1,N2=N-2                          0003000
      4*       PARAMETER ND=2*M*N-M1-N1                                       0004000
      5*       DIMENSION DATA1(ND),DATA2(ND),DATA3(ND)                        0005000
      6*       COMMON/ONE/VR1(M,N1),VT1(M,N1),VZ1(M1,N),B1(M1,N1),VR2(M,N1),  0006000
      7*      1           VT2(M,N1),VZ2(M1,N),B2(M1,N1),VR3(M,N1),VT3(M,N1),  0007000
      8*      2           VZ3(M1,N),B3(M1,N1),P(M1,N1)                        0008000
      9*       EQUIVALENCE (DATA1,VR1),(DATA2,VR2),(DATA3,VR3)                0009000
     10*       DATA DATA1/ND*0./,DATA2/ND*0./,DATA3/ND*0./                    0010000
     11*       COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N) 0011000
     12*       COMMON/THR/RHO,PPR(N1),BV2(N),ALPHA,BNDA,BNDB,CORI,G,RK(M),ZK(N) 0012000
     13*       COMMON/FOR/DELT,XTIME,ITIME,ISTEP,ISMO,ITAPE,TBV               0013000
     14*       CALL INDUMP                                                    0014000
     15*   100 FORMAT(I4)                                                     0015000
     16*       READ(5,100)ITIME                                               0016000
     17*       READ(5,100)ITER                                                0017000
     18*       READ(5,100)IOUT                                                0018000
     19*       READ(5,100)ISMO                                                0019000
     20*       ISTEP=0                                                        0020000
     21*       READ(5,100)ITAPE                                               0021000
     22*       CALL INIT                                                      0022000
     23*       IF(ITIME.EQ.0)GO TO 10                                         0023000
     24* C                                                                    0024000
     25* C                    CONTINUED INTEGRATION FROM A HISTORY TAPE       0025000
     26* C                                                                    0026000
     27*       READ(1)ITIME,DATA1,DATA2,P                                     0027000
     28*       GO TO 20                                                       0028000
     29*    10 CALL START                                                     0029000
     30*    20 XTIME=ITIME*3600.                                              0030000
     31* C                                                                    0031000
     32* C                    PRINT OUT INITIAL FIELDS                        0032000
     33* C                                                                    0033000
     34*       CALL PUTOUT                                                    0034000
     35*       IF(ITER.EQ.0)STOP                                              0035000
     36*       DO 90 ISTEP=1,ITER                                             0036000
     37* C                                                                    0037000
     38* C                 COMPUTE ALL INVISCID TERMS                         0038000
     39* C                                                                    0039000
     40*       CALL ADVECT                                                    0040000
     41* C                                                                    0041000
     42* C                    COMPUTE VISCOUS TERMS                           0042000
     43* C                                                                    0043000
     44*       CALL DIFF                                                      0044000
     45* C                                                                    0045000
     46* C                    ADD ACC PRESSURE GRADIENT FORCES TO TENDENCIES   0046000
     47* C                    DIAGNOSE (RECOVER) THE PRESSURE FIELD           0047000
     48* C                                                                    0048000
     49*       CALL PRESS                                                     0049000
     50* C                                                                    0050000
     51* C                    MARCHING IN TIME                                0051000
     52* C                    FIRST TIME STEP IS FORWARD IF START IS CALLED   0052000
     53* C                                                                    0053000
     54*       IF(ISTEP.EQ.1.AND.ITIME.EQ.0)DELT=0.5*DELT                     0054000
     55*       CALL FWRD                                                      0055000
     56*       IF(ISTEP.EQ.1.AND.ITIME.EQ.0)DELT=2.*DELT                      0056000
     57* C                                                                    0057000
     58* C                    DEFINE BOUNDARY VALUES FOR VELOCITY             0058000
     59* C                                                                    0059000
     60*       CALL BOUNDV                                                    0060000
     61* C                                                                    0061000
     62* C                    CHECK IF DELT IS STABLE                         0062000
     63* CC                                                                   0063000
     64*       CALL CHECK                                                     0064000
     65*       XTIME=XTIME+DELT                                               0065000
     66*       ITIME=XTIME/3600.                                              0066000
     67* C                                                                    0067000
     68* C                    PRINT OUT RESULTS EVERY IPLT STEPS              0068000
     69* C                                                                    0069000
     70*       IF(MOD(ISTEP,IPLT).EQ.0)CALL PUTOUT                            0070000
     71* C                                                                    0071000
     72* C                    WRITE HISTORY TAPE EVERY ITAPE STEPS            0072000
     73* C                                                                    0073000
     74*       IF(MOD(ISTEP,ITAPE).EQ.0)WRITE(2)ITIME,DATA1,DATA2,P           0074000
     75*    90 CONTINUE                                                       0075000
     76*       STOP                                                           0076000
     77*       END                                                            0077000
```

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CARD IMAGE FILE EDITOR(CIFEM) -- VERSION 05.29  DATE=10/26/82       TIME=14:12:12:99

*** MEMBER INIT

                SUBROUTINE  INIT                                                        00010000
                PARAMETER MM=21,NN=1                                                    00020000
                PARAMETER M1=M-1,M2=M-2,N1=N-1,N2=N-2                                   00030000
                COMMON/ONE/V01(M,N1),VT1(M,N1),VZ1(M1,N),B1(M1,N1),VR2(M,N1),           00040000
               1           VT2(M,N1),VZ2(M1,N),B2(M1,N1),VR3(M,N1),VT3(M,N1),           00050000
               2           VZ3(M1,N),B3(M1,N1),P(M1,N1)                                 00060000
                COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N)      00070000
                COMMON/THR/RHO,EMGR(N1),RV2(N),ALPHA,BNDA,BNDR,CGRI,G,HK(M),ZK(N)       00080000
                COMMON/FOR/DELT,XTIME,ITIME,ISTEP,ISW0,ITAPE,TBV                        00090000
                PARAMETER MP=M+1,NP=N+1                                                 00100000
                PARAMETER NBLK=2,NBLK1=NBLK-1                                           00110000
                PARAMETER MP1=MP-1,MP2=MP-2,NP1=NP-1,NP2=NP-2                           00120000
                REAL*8 RCOR,RINV,RINV1,RTILDA                                           00130000
                COMMON/FVP/RINV(MP2,MP2,NBLK),RINV1(MP2,MP2,NBLK1),RCOR(MP,3),          00140000
               1           RTILDA(MP2),F(MP,NP),NRSIZ2(NBLK),IS(NBLK),SUMF(NBLK),       00150000
               2           IE(NBLK),FI1(MP),FIN(MP),FZ1(NP),FZM(NP),AX(MP),AY(NP),      00160000
               3           BB(MP,NP),CX(MP),CY(NP)                                      00170000
C                                                                                       00180000
C                 INITIALIZE ALL DEPENDENT VARIABLES AND CONSTANTS                      00190000
C                                                                                       00200000
C                                                                                       00210000
C                  ALPHA IS THE NONDIMENSIONAL SMOOTHING COEF.                          00220000
C                  FOR TIME SMOOTHING IN SUBROUTINE FAMRO                               00230000
C                                                                                       00240000
                DELT=900.                                                               00250000
                ALPHA=0.10                                                              00260000
                GRAV=0.                                                                 00270000
                LAT=30                                                                  00280000
                CORI=2.*7.2722E-5*SIN(LAT*3.14159/180.)                                 00290000
C                                                                                       00300000
C                       DEFINE RADII AT GRID POINTS AND ALL GRID INTERVALS              00310000
C                                                                                       00320000
                DO 10 I=1,M1                                                            00330000
             10 DR1(I)=20.ES                                                            00340000
                R1(1)=0.                                                                00350000
                DO 20 I=2,M                                                             00360000
             20 R1(I)=R1(I-1)+DR1(I-1)                                                  00370000
                DO 30 I=1,M1                                                            00380000
             30 R2(I)=0.5*(R1(I)+R1(I+1))                                               00390000
                DR2(1)=2.*(R2(1)-R1(1))                                                 00400000
                DR2(M)=2.*(R1(M)-R2(M1))                                                00410000
                DO 40 I=2,M1                                                            00420000
             40 DR2(I)=R2(I)-R2(I-1)                                                    00430000
C               MAX=MAXMAG(DR1)                                                         00440000
C               DRMAX=DR1(MAX)                                                          00450000
C                                                                                       00460000
C                       DEFINE ALL DZ'S                                                 00470000
C                                                                                       00480000
                DO 100 J=1,N                                                            00490000
            100 Z1(J)=(J-1)*200.ES                                                      00500000
                DO 110 J=1,N1                                                           00510000
            110 DZ1(J)=Z1(J+1)-Z1(J)                                                    00520000
                DZ2(1)=2.*(0.5*(Z1(1)-Z1(1)))                                           00530000
                Z2(1)=0.5*DZ2(1)                                                        00540000
                DO 120 J=2,N1                                                           00550000
                DZ2(J)=0.5*(DZ1(J)+DZ1(J-1))                                            00560000
            120 Z2(J)=Z2(J-1)+DZ2(J)                                                    00570000
                DZ2(N)=2.*(Z1(N)-Z1(N-1)-0.5*DZ1(N1))                                   00580000
C               MAX=MAXMAG(DZ1)                                                         00590000
C               DZMAX=DZ1(MAX)                                                          00600000
C                                                                                       00610000
C                       DEFINE CONSTANTS FOR SEVP SOLVER                                00620000
C                                                                                       00630000
                AX(1)=0.                                                                00640000
                CX(MP)=0.                                                               00650000
                AY(1)=0.                                                                00660000
                CY(NP)=0.                                                               00670000
                DO 50 I=1,M1                                                            00680000
                AX(I+1)=R1(I)/(0.5*(R1(I)+R1(I+1))*DR1(I)*DR2(I))                       00690000
             50 CX(I+1)=R1(I+1)/(0.5*(R1(I)+R1(I+1))*DR1(I)*DR2(I+1))                   00700000
                DO 60 J=1,N1                                                            00710000
                AY(J+1)=1./(DZ1(J)*DZ2(J))                                              00720000
             60 CY(J+1)=1./(DZ1(J)*DZ2(J+1))                                            00730000
                DO 70 J=1,NP                                                            00740000
                DO 70 I=1,MP                                                            00750000
             70 BB(I,J)=CX(I)+AX(I)+CY(J)+AY(J)                                         00760000
                NSIZE=N1/NBLK+MPC(N1,2)                                                 00770000
                DO 80 NB=1,NBLK1                                                        00780000
             80 NRSIZ2(NB)=NSIZE                                                        00790000
                NBSIZ2(NBLK)=N1-(NBLK-1)*NSIZE*NBLK1
```

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CARD IMAGE FILE EDITOP(CIFEM) -- VERSION 05.29  DATE=10/26/82       TIME=14:12:12:99

*** MEMBER INIT

                                                                                0080000
      81* C                                                                     0081000
      82* C                     A AND B ARE CONSTANT USED IN SUBROUTINE BOUNDV   0082000
      83* C                     FOR CONSTANT DIV. AND VERT. CONDITIONS           0083000
      84* C                                                                     0084000
      85*       BNDA=M1(M1)/R1(M)                                               0085000
      86*       BNDB=(R1(M1)*R1(M))*DR1(M1)/((R1(M1)+R1(M2))*R1(M)*DR1(M2))     0086000
      87*       BNDB=0.                                                         0087000
      88* C                                                                     0088000
      89* C                     DEFINE DENSITY RELATED CONSTANTS                0089000
      90* C                                                                     0090000
      91*       RM=1.                                                           0091000
      92*       DO 130 J=1,N                                                    0092000
      93*   130 BV2(J)=1.E-6                                                    0093000
      94*       TBV=0.                                                          0094000
      95*       DO 135 J=1,N                                                    0095000
      96*   135 TBV=AMAX1(TBV,BV2(J))                                           0096000
      97*       TBV=1./SQRT(TBV)                                                0097000
      98* C                                                                     0098000
      99* C                     DEFINE HORIZONTAL AND VERTICAL DIFFUSION COEFFIENTS 0099000
     100* C                                                                     0100000
     101*       CREFM=0.002*DR1(1)**2/DELT                                      0101000
     102*       COEFZ=0.001*DZ1(1)**2/DELT                                      0102000
     103*       DO 140 I=1,M1                                                   0103000
     104*   140 HK(I)=COEFM*(1.+5.*EXP(-FLOAT(M1-I)/7.))                        0104000
     105*       DO 150 J=1,N1                                                   0105000
     106*   150 ZK(J)=COEFZ*(1.+5.*(EXP(-FLOAT(J-1)/5.)+EXP(-FLOAT(N1-J)/5.))) 0106000
     107*       RETURN                                                          0107000
     108*       END                                                             0108000
```

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CARD IMAGE FILE EDITOR(CIFEM) -- VERSION 05.29  DATE=10/26/82       TIME=14:12:12:99

*** MEMBER START

      1*       SUBROUTINE START                                                        0001000
      2*       PARAMETER M=21,N=21                                                     0002000
      3*       PARAMETER M1=M+1,M2=M+2,N1=N+1,N2=N+2                                   0003000
      4*       COMMON/ONE/VR1(M,N1),VT1(M,N1),VZ1(M1,N),R1(M1,N1),VR2(M,N1),           0004000
      5*      1           VT2(M,N1),VZ2(M1,N),B2(M1,N1),VR3(M,N1),VT3(M,N1),         0005000
      6*      2           VZ3(M1,N),B3(M1,N1),P(M1,N1)                               0006000
      7*       COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N)     0007000
      8*       COMMON/THR/RHO,EPSR(N1),RV2(N),ALPHA,BNDA,BNDB,CORI,G,RK(M),ZK(N)      0008000
      9*       PARAMETER ND=2*M*N1+M1*N+M1*N1                                          0009000
     10*       DIMENSION DATA1(ND),DATA2(ND)                                           0010000
     11*       EQUIVALENCE (DATA1,VR1),(DATA2,VR2)                                     0011000
     12* C                                                                            0012000
     13* C                    INITIALIZE MASS FIELDS FOR A THEORETICAL RING            0013000
     14* C                                                                            0014000
     15*       I11=1                                                                   0015000
     16*       I12=13                                                                  0016000
     17*       I21=I12+1                                                               0017000
     18*       I22=M1                                                                  0018000
     19*       AMAG=0.0002                                                             0019000
     20*       DO 10 I=I11,I12                                                         0020000
     21*    10 B1(I,N1)=AMAG*COS(FLOAT(I-I11)/8.*3.14159)*G/RHO                        0021000
     22*       DO 30 I=I21,I22                                                         0022000
     23*    30 B1(I,N1)=B1(I12,N1)*EXP(-FLOAT(I-I21+1)/4.)                             0023000
     24*       DO 40 J=1,N2                                                            0024000
     25*       FACT=EXP(FLOAT(J-N1)/5.)                                                0025000
     26*       DO 40 I=1,M1                                                            0026000
     27*    40 B1(I,J)=B1(I,N1)*FACT                                                   0027000
     28* C                                                                            0028000
     29* C                    PRESSURE IS OBTAINED HYDROSTATICALLY FROM BUOYANCY       0029000
     30* C                                                                            0030000
     31*       DO 50 I=1,M1                                                            0031000
     32*    50 P(I,1)=0.5*RHO*DZ2(1)*B1(I,1)                                           0032000
     33*       DO 60 J=2,N1                                                            0033000
     34*       DO 60 I=1,M1                                                            0034000
     35*    60 P(I,J)=P(I,J-1)+0.5*RHO*DZ2(J)*(B1(I,J)+B1(I,J-1))                      0035000
     36* C                                                                            0036000
     37* C                    TANGENTIAL VELOCITY IS IN GRADIENT BALANCE WITH MASS     0037000
     38* C                                                                            0038000
     39*       DO 70 J=1,N1                                                            0039000
     40*       DO 70 I=2,M1                                                            0040000
     41*       PGF=(P(I,J)-P(I-1,J))/(RHO*DR2(I))                                      0041000
     42*       RAD=(0.5*CORI*R1(I))**2+R1(I)*PGF                                       0042000
     43*       JJ=J                                                                    0043000
     44*       II=I                                                                    0044000
     45*       IF(RAD.LT.0.)GO TO 100                                                  0045000
     46*    70 VT1(I,J)=-0.5*CORI*R1(I)+SQRT(RAD)                                      0046000
     47* C                                                                            0047000
     48* C                    SET DATA2=DATA1 FOR LEAPFROG                            0048000
     49* C                                                                            0049000
     50*       DO 80 I=1,ND                                                            0050000
     51*    80 DATA2(I)=DATA1(I)                                                       0051000
     52*       CALL BOUNDV                                                             0052000
     53*       DO 90 I=1,ND                                                            0053000
     54*    90 DATA1(I)=DATA2(I)                                                       0054000
     55*       RETURN                                                                  0055000
     56*   100 PRINT 110,II,JJ,PGF,RAD                                                0056000
     57*   110 FORMAT(' RADICAL IN SUBROUTINE START IS NEGATIVE AT (I,J)=',2I5,       0057000
     58*      1' PGF, RAD =',1P2E12.3)                                                0058000
     59*       STOP                                                                    0059000
     60*       END                                                                     0060000
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CARD IMAGE FILE EDITOR(CIFEM) -- VERSION 05.29  DATE=10/26/82       TIME=10:12:12:99

*** MEMBER BOUNDV

  1*       SUBROUTINE BOUNDV                                                      0001000
  2*       PARAMETER M2=1,N=1                                                     0002000
  3*       PARAMETER M1=M-1,M2=M-2,N1=N-1,N2=N-2                                  0003000
  4*       COMMON/ONE/VR1(M,N),VT1(M,N),VZ1(M1,N),R1(M1,N),VR2(M,N),              0004000
  5*      1           VT2(M,N),VZ2(M1,N),R2(M1,N),VR3(M,N),VT3(M,N),             0005000
  6*      2           VZ3(M1,N),R3(M1,N),P(M1,N)                                 0006000
  7*       COMMON/TWO/Z1(M),Z2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N)     0007000
  8*       COMMON/THR/RM,RMM,DMDR(N1),BV2(N),ALPHA,BNDA,BNDB,CORI,G,FK(M),ZK(N)  0008000
  9* C                                                                            0009000
 10* C                  LATERAL BOUNDARY FOR TANGENTIAL AND RADIAL VELOCITIES     0010000
 11* C                  ASSUMING CONTINUOUS VORTICITY AND DIVERGENCE               0011000
 12* C                                                                            0012000
 13*       DO 10 J=1,N1                                                           0013000
 14*       VR2(M,J)=BNDA*VR2(M1,J)+BNDB*(R1(M1)*VR2(M1,J)-R1(M2)*VR2(M2,J))       0014000
 15*    10 VT2(M,J)=BNDA*VT2(M1,J)+BNDB*(R1(M1)*VT2(M1,J)-R1(M2)*VT2(M2,J))       0015000
 16*       RETURN                                                                 0016000
 17*       END                                                                    0017000
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CARD IMAGE FILE EDITOR(CIFED) -- VERSION 05.29  DATE=10/26/82       TIME=14:12:12:99

*** MEMBER= DIFF

      1*        SUBROUTINE DIFF                                                 0001000
      2* C                                                                       0002000
      3* C                     COMPUTE THE DIFFUSION TERMS                       0003000
      4* C                                                                       0004000
      5*        PARAMETER M=21,N=21                                             0005000
      6*        PARAMETER M1=M-1,M2=M-2,N1=N-1,N2=N-2                           0006000
      7*        COMMON/PHI/VR1(M,N1),VT1(M,N1),VZ1(M1,N),B1(M1,N1),VR2(M,N1),   0007000
      8*       1           VT2(M,N1),VZ2(M1,N),B2(M1,N1),VR3(M,N1),VT3(M,N1),   0008000
      9*       2           VZ3(M1,N),B3(M1,N1),P(M1,N1)                         0009000
     10*        COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N) 0010000
     11*        COMMON/THR/RHO,BMER(N1),BV2(N),ALPHA,BNDA,BNDB,CORI,G,HK(M),ZK(N) 0011000
     12*        DIMENSION VR(M,N1),VT(M,N1),VZ(M1,N),B(M1,N1)                   0012000
     13*        EQUIVALENCE (VR,VR1),(VT,VT1),(VZ,VZ1),(B,B1)                   0013000
     14* C                                                                       0014000
     15* C                     HORIZONTAL DIFFUSION OF RADIAL VELOCITY           0015000
     16* C                                                                       0016000
     17*        DO 10 J=1,N1                                                    0017000
     18*        DO 10 I=2,M1                                                    0018000
     19*     10 VR3(I,J)=VR3(I,J)+HK(I)*(((VR(I+1,J)-VR(I,J))/DR1(I)            0019000
     20*       1        -(VR(I,J)-VR(I-1,J))/DR1(I-1))/DR2(I)-VR(I,J)/(R1(I)*R1(I)) 0020000
     21*       2          +0.5*((VR(I+1,J)-VR(I,J))/(DR1(I)*R2(I))              0021000
     22*       3          +(VR(I,J)-VR(I-1,J))/(DR1(I-1)*R2(I-1))))             0022000
     23* C                                                                       0023000
     24* C                     HORIZONTAL DIFFUSION OF TANGENTIAL VELOCITY       0024000
     25* C                                                                       0025000
     26*        DO 20 J=1,N1                                                    0026000
     27*        DO 20 I=2,M1                                                    0027000
     28*     20 VT3(I,J)=VT3(I,J)+HK(I)*(((VT(I+1,J)-VT(I,J))/DR1(I)            0028000
     29*       1        -(VT(I,J)-VT(I-1,J))/DR1(I-1))/DR2(I)-VT(I,J)/(R1(I)*R1(I)) 0029000
     30*       2          +0.5*((VT(I+1,J)-VT(I,J))/(DR1(I)*R2(I))              0030000
     31*       3          +(VT(I,J)-VT(I-1,J))/(DR1(I-1)*R2(I-1))))             0031000
     32* C                                                                       0032000
     33* C                     HORIZONTAL DIFFUSION OF VERTICAL VELOCITY         0033000
     34* C                                                                       0034000
     35*        DO 30 J=2,N1                                                    0035000
     36*        DO 30 I=2,M2                                                    0036000
     37*     30 VZ3(I,J)=VZ3(I,J)+HK(I)*(((VZ(I+1,J)-VZ(I,J))/DR2(I+1)          0037000
     38*       1          -(VZ(I,J)-VZ(I-1,J))/DR2(I))/DR1(I)                   0038000
     39*       2          +0.5*((VZ(I+1,J)-VZ(I,J))/(DR2(I+1)*R1(I+1))          0039000
     40*       3          +(VZ(I,J)-VZ(I-1,J))/(DR2(I)*R1(I))))                 0040000
     41*        DO 40 J=2,N1                                                    0041000
     42*     40 VZ3(1,J)=VZ3(1,J)+HK(1)*((VZ(2,J)-VZ(1,J))/(DR2(1)*DR1(1))      0042000
     43*       1          +0.5*(VZ(2,J)-VZ(1,J))/(DR2(2)*R1(2)))                0043000
     44*        DO 50 J=2,N1                                                    0044000
     45*     50 VZ3(M1,J)=VZ3(M1,J)+HK(M1)*((-VZ(M1,J)+VZ(M2,J))/(DR2(M1)*DR1(M1)) 0045000
     46*       1          +(-VZ(M1,J)+VZ(M2,J))/(DR2(M1)*R1(M1)))               0046000
     47* C                                                                       0047000
     48* C                     HORIZONTAL DIFFUSION OF B                         0048000
     49* C                                                                       0049000
     50*        DO 60 J=1,N1                                                    0050000
     51*        DO 60 I=2,M2                                                    0051000
     52*     60 B3(I,J)=B3(I,J)+HK(I)*(((B(I+1,J)-B(I,J))/DR2(I+1)              0052000
     53*       1          -(B(I,J)-B(I-1,J))/DR2(I))/DR1(I)                     0053000
     54*       2          +0.5*((B(I+1,J)-B(I,J))/(DR2(I+1)*R1(I+1))            0054000
     55*       3          +(B(I,J)-B(I-1,J))/(DR2(I)*R1(I))))                   0055000
     56*        DO 70 J=1,N1                                                    0056000
     57*     70 B3(1,J)=B3(1,J)+HK(1)*((B(2,J)-B(1,J))/(DR2(2)*DR1(1))          0057000
     58*       1          +0.5*(B(2,J)-B(1,J))/(DR2(2)*R1(2)))                  0058000
     59*        DO 80 J=1,N1                                                    0059000
     60*     80 B3(M1,J)=B3(M1,J)+HK(M1)*((-B(M1,J)+B(M2,J))/(DR2(M1)*DR1(M1))  0060000
     61*       1          -(B(M1,J)-B(M2,J))/(DR2(M1)*R1(M1)))                  0061000
     62* C                                                                       0062000
     63* C                     VERTICAL DIFFUSION OF RADIAL VELOCITY             0063000
     64* C                                                                       0064000
     65*        DO 90 J=2,N2                                                    0065000
     66*        DO 90 I=2,M1                                                    0066000
     67*     90 VR3(I,J)=VR3(I,J)+ZK(J)*((VR(I,J+1)-VR(I,J))/DZ2(J+1)           0067000
     68*       1          -(VR(I,J)-VR(I,J-1))/DZ2(J))/DZ1(J)                   0068000
     69*        DO 100 I=2,M1                                                   0069000
     70*    100 VR3(I,1)=VR3(I,1)+ZK(1)*(VR(I,2)-VR(I,1))/(DZ2(2)*DZ1(1))       0070000
     71*        DO 110 I=2,M1                                                   0071000
     72*    110 VR3(I,N1)=VR3(I,N1)+ZK(N1)*(-VR(I,N1)+VR(I,N2))/(DZ2(N1)*DZ1(N1)) 0072000
     73* C                                                                       0073000
     74* C                     VERTICAL DIFFUSION OF TANGENTIAL VELOCITY         0074000
     75* C                                                                       0075000
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CARD IMAGE FILE EDITOR(CIFEM) -- VERSION 05.29  DATE=10/26/82       TIME=14:12:12:99

*** MEMBER DIFF

                76*       DO 120 J=2,N2                                                          0076000
                77*       DO 120 I=2,M1                                                          0077000
                78*   120 VT3(I,J)=VT3(I,J)+ZK(J)*((VT(I,J+1)-VT(I,J))/DZ2(J+1)                  0078000
                79*      1          -(VT(I,J)-VT(I,J-1))/DZ2(J))/DZ1(J)                         0079000
                80*       DO 130 I=2,M1                                                          0080000
                81*   130 VT3(I,1)=VT3(I,1)+ZK(1)*(VT(I,2)-VT(I,1))/(DZ2(2)*DZ1(1))              0081000
                82*       DO 140 I=2,M1                                                          0082000
                83*   140 VT3(I,N1)=VT3(I,N1)+ZK(N1)*(-VT(I,N1)+VT(I,N2))/(DZ2(N1)*DZ1(N1))     0083000
                84*                                                                            0084000
                85* C                                                                          0085000
                86* C                    VERTICAL DIFFUSION OF VERTICAL VELOCITY               0086000
                87* C                                                                          0087000
                88*       DO 150 J=2,N1                                                        0088000
                89*       DO 150 I=1,M1                                                        0089000
                90*   150 VZ3(I,J)=VZ3(I,J)+ZK(J)*((VZ(I,J+1)-VZ(I,J))/DZ1(J)                  0090000
                91*      1          -(VZ(I,J)-VZ(I,J-1))/DZ1(J-1))/DZ2(J)                       0091000
                92* C                                                                          0092000
                93* C                    VERTICAL DIFFUSION OF B                               0093000
                94* C                                                                          0094000
                95*       DO 160 J=2,N2                                                        0095000
                96*       DO 160 I=1,M1                                                        0096000
                97*   160 B3(I,J)=B3(I,J)+ZK(J)*((B1(I,J+1)-B(I,J))/DZ2(J+1)                   0097000
                98*      1          -(B(I,J)-B(I,J-1))/DZ2(J))/DZ1(J)                           0098000
                99*       DO 170 I=1,M1                                                        0099000
               100*   170 B3(I,1)=B3(I,1)+ZK(1)*(B(I,2)-B(I,1))/(DZ2(2)*DZ1(1))                0100000
               101*       DO 180 I=1,M1                                                        0101000
               102*   180 B3(I,N1)=B3(I,N1)+ZK(N1)*(-B(I,N1)+B(I,N2))/(DZ2(N1)*DZ1(N1))       0102000
               103*       RETURN                                                               0103000
               104*       END                                                                  0104000
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CARD IMAGE FILE EDITOR(CIFEM) -- VERSION 05.29  DATE=10/26/82       TIME=14112112:19

*** MEMBER FRWRD

                1*        SUBROUTINE FRWRL                                                      0001000
                2*        PARAMETER M=21,N=21                                                   0002000
                3*        PARAMETER M1=M+1,M2=M+2,N1=N+1,N2=N+2                                 0003000
                4*        PARAMETER ND=2*M*N1+M1*N+M1*N1                                        0004000
                5*        COMMON/ONE/DATA1(ND),DATA2(ND),DATA3(ND),P(M1,N1)                     0005000
                6*        COMMON/TWR/RHO,EMER(N1),BV2(N),ALPHA,BNDA,BNDB,CSRI,G,HX(M),ZK(N)    0006000
                7*        COMMON/FOR/DELT,XTIME,ITIME,ISTEP,ISMO,ITAPE,TBV                      0007000
                8* C                                                                             0008000
                9* C                    REPLACE DATA3 WITH THE NEW VALUES                        0009000
               10* C                                                                             0010000
               11*        DO 10 I=1,ND                                                          0011000
               12*     10 DATA3(I)=DATA1(I)+2.*DELT*DATA3(I)                                    0012000
               13* C                                                                             0013000
               14* C                    TIME SMOOTHING                                           0014000
               15* C                                                                             0015000
               16*        IF(MOD(ISTEP,ISMO).NE.0)GO TO 30                                      0016000
               17*        DO 20 I=1,ND                                                          0017000
               18*     20 DATA2(I)=DATA2(I)+(DATA1(I)-DATA3(I)-2.*DATA2(I))*ALPHA            0018000
               19*     30 CONTINUE                                                              0019000
               20* C                                                                             0020000
               21* C                    FORWARD MARCHING                                         0021000
               22* C                                                                             0022000
               23*        DO 40 I=1,ND                                                          0023000
               24*     40 DATA1(I)=DATA2(I)                                                     0024000
               25*        DO 50 I=1,ND                                                          0025000
               26*     50 DATA2(I)=DATA3(I)                                                     0026000
               27* C                                                                             0027000
               28* C                    ZERO OUT DATA3 FOR NEXT STEP                             0028000
               29* C                                                                             0029000
               30*        DO 60 I=1,ND                                                          0030000
               31*     60 DATA3(I)=0.                                                           0031000
               32*        RETURN                                                                0032000
               33*        END                                                                   0033000
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CARD IMAGE FILE EDITOR(CIFED) -- VERSION 05.29  DATE=10/26/82       TIME=14:12:12:99

*** MEMBER CHECK

                1*       SUBROUTINE CHECK                                                        0001000
                2*       PARAMETER M=21,N=21                                                     0002000
                3*       PARAMETER M1=M-1,M2=M-2,N1=N-1,N2=N-2                                   0003000
                4*       COMMON/ONE/VR1(M,N1),VT1(M,N1),VZ1(M1,N),R1(M1,N1),VR2(M,N1),           0004000
                5*      1           VT2(M,N1),VZ2(M1,N),R2(M1,N1),VR3(M,N1),VT3(M,N1),          0005000
                6*      2           VZ3(M1,N),R3(M1,N1),P(M1,N1)                                0006000
                7*       COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N)      0007000
                8*       COMMON/FOR/DELT,XTIME,ITIME,ISTEP,ISMO,ITAPE,TBV                        0008000
                9*       DIMENSION WORK1(M),WORK2(N)                                             0009000
               10*       DO 10 J=1,N1                                                            0010000
               11*       DO 20 I=1,M                                                             0011000
               12*    20 WORK1(I)=DR2(I)/AMAX1(1., VR2(I,J))                                     0012000
               13*       MIN=MINLOC(WORK1)+1                                                     0013000
               14*       DT=WORK1(MIN)*0.9                                                       0014000
               15*       DT=AMIN1(DT,DELT)                                                       0015000
               16*    10 CONTINUE                                                                0016000
               17*       DO 40 I=1,M1                                                            0017000
               18*       DO 30 J=1,N                                                             0018000
               19*    30 WORK2(J)=DZ2(J)/AMAX1(1.,VZ2(I,J))                                      0019000
               20*       MIN=MINLOC(WORK2)+1                                                     0020000
               21*       DT=WORK2(MIN)*0.9                                                       0021000
               22*       DT=AMIN1(DT,DELT)                                                       0022000
               23*    40 CONTINUE                                                                0023000
               24*       DT=AMIN1(DT,TBV)                                                        0024000
               25*       IF(DT.GE.DELT)RETURN                                                    0025000
               26*       DELT=0.75*DELT                                                          0026000
               27*       PRINT 100,DELT                                                          0027000
               28*   100 FORMAT(///////,'*******DELT IS CHANGED TO',1PE11.2,' ***********')      0028000
               29*       RETURN                                                                  0029000
               30*       END                                                                     0030000
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CARD IMAGE FILE EDITOR(CIFEM) -- VERSION 05.29  DATE=10/26/82        TIME=14:12:12:99

*** MEMBER ZILCH

                1*        SUBROUTINE ZILCH(A,N)                                  0001000
                2*        DIMENSION A(N)                                         0002000
                3*        DO 10 I=1,N                                            0003000
                4*     10 A(I)=0.                                                0004000
                5*        RETURN                                                 0005000
                6*        END                                                    0006000
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CARD IMAGE FILE EDITOR(CIFER) -- VERSION 05.29  DATE=10/26/82       TIME=14:12:12:99

*** MEMBER ADVECT

      1*       SUBROUTINE ADVECT                                                      0001000
      2* C                                                                           0002000
      3* C                    COMPUTE THE ADVECTIVE TERMS                            0003000
      4* C                                                                           0004000
      5*       PARAMETER M=21,N=21                                                    0005000
      6*       PARAMETER M1=M-1,M2=M-2,N1=N-1,N2=N-2                                  0006000
      7*       COMMON/ONE/VR1(M,N1),VT1(M,N1),VZ1(M1,N),B1(M1,N1),VR2(M,N1),          0007000
      8*      1           VT2(M,N1),VZ2(M1,N),B2(M1,N1),VR3(M,N1),VT3(M,N1),        0008000
      9*      2           VZ3(M1,N),B3(M1,N1),P(M1,N1)                               0009000
     10*       COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N)     0010000
     11*       COMMON/THR/RHO,GMGR(N1),BV2(N),ALPHA,BNDA,BNDB,CORI,G,PK(M1),ZK(N)    0011000
     12*       DIMENSION VR(M,N1),VT(M,N1),VZ(M1,N),B(M1,N1)                          0012000
     13*       EQUIVALENCE (VR,VR2),(VT,VT2),(VZ,VZ2),(B,B2)                          0013000
     14* C                                                                           0014000
     15* C                    HORIZONTAL ADVECTION FOR RADIAL VELOCITY               0015000
     16* C                                                                           0016000
     17*       DO 10 J=1,N1                                                           0017000
     18*       DO 10 I=2,M1                                                           0018000
     19*    10 VR3(I,J)=-0.25*((VR(I,J)+VR(I-1,J))*(VR(I,J)-VR(I-1,J))/DR1(I-1)       0019000
     20*      1          +(VR(I+1,J)+VR(I,J))*(VR(I+1,J)-VR(I,J))/DR1(I))           0020000
     21*      2          +VR3(I,J)                                                   0021000
     22* C                                                                           0022000
     23* C                    HORIZONTAL ADVECTION FOR TANGENTIAL VELOCITY           0023000
     24* C                                                                           0024000
     25*       DO 20 J=1,N1                                                           0025000
     26*       DO 20 I=2,M1                                                           0026000
     27*    20 VT3(I,J)=-0.25*((VR(I,J)+VR(I-1,J))*(VT(I,J)-VT(I-1,J))/DR1(I-1)       0027000
     28*      1          +(VR(I+1,J)+VR(I,J))*(VT(I+1,J)-VT(I,J))/DR1(I))           0028000
     29*      2          +VT3(I,J)                                                   0029000
     30* C                                                                           0030000
     31* C                    HORIZONTAL ADVECTION FOR VERTICAL VELOCITY             0031000
     32* C                                                                           0032000
     33*       DO 30 J=2,N1                                                           0033000
     34*       DO 30 I=2,M2                                                           0034000
     35*    30 VZ3(I,J)=-0.25*((VR(I,J)+VR(I,J-1))*(VZ(I,J)-VZ(I-1,J))/DR2(I)       0035000
     36*      1          +(VR(I+1,J)+VR(I+1,J-1))*(VZ(I+1,J)-VZ(I,J))/DR2(I+1))     0036000
     37*      2          +VZ3(I,J)                                                   0037000
     38*       DO 40 J=2,N1                                                           0038000
     39*    40 VZ3(1,J)=-0.25*(VR(2,J)+VR(2,J-1))*(VZ(2,J)-VZ(1,J))/DR2(2)           0039000
     40*      1          +VZ3(1,J)                                                   0040000
     41*       DO 50 J=2,N1                                                           0041000
     42*    50 VZ3(M1,J)=-0.25*(VR(M1,J)+VR(M1,J-1))*(VZ(M1,J)-VZ(M2,J))/DR2(M1)     0042000
     43*      1          +VZ3(M1,J)                                                  0043000
     44* C                                                                           0044000
     45* C                    HORIZONTAL ADVECTION FOR BUOYANCY                      0045000
     46* C                                                                           0046000
     47*       DO 60 J=1,N1                                                           0047000
     48*       DO 60 I=2,M2                                                           0048000
     49*    60 B3(I,J)=B3(I,J)-0.5*(VR(I,J)*(B(I,J)-B(I-1,J))/DR2(I)                 0049000
     50*      1          +VR(I+1,J)*(B(I+1,J)-B(I,J))/DR2(I+1))                      0050000
     51*       DO 70 J=1,N1                                                           0051000
     52*    70 B3(1,J)=B3(1,J)-0.5*VR(2,J)*(B(2,J)-B(1,J))/DR2(2)                    0052000
     53*       DO 80 J=1,N1                                                           0053000
     54*    80 B3(M1,J)=B3(M1,J)-0.5*VR(M1,J)*(B(M1,J)-B(M2,J))/DR2(M1)              0054000
     55* C                                                                           0055000
     56* C                    VERTICAL ADVECTION FOR RADIAL VELOCITY                 0056000
     57* C                                                                           0057000
     58*       DO 90 J=2,N2                                                           0058000
     59*       DO 90 I=2,M1                                                           0059000
     60*    90 VR3(I,J)=VR3(I,J)-0.25*((VZ(I-1,J)+VZ(I,J))*(VR(I,J)-VR(I,J-1))      0060000
     61*      1          /DZ2(J)+(VZ(I,J+1)+VZ(I-1,J+1))*(VR(I,J+1)-VR(I,J))        0061000
     62*      2          /DZ2(J+1))                                                  0062000
     63*       DO 95 I=2,M1                                                           0063000
     64*    95 VR3(I,1)=VR3(I,1)-0.25*(VZ(I,2)+VZ(I-1,2))*(VR(I,2)-VR(I,1))          0064000
     65*      1          /DZ2(2)                                                     0065000
     66*       DO 96 I=2,M1                                                           0066000
     67*    96 VR3(I,N1)=VR3(I,N1)-0.25*(VZ(I-1,N1)+VZ(I,N1))*(VR(I,N1)-VR(I,N2))   0067000
     68*      1          /DZ2(N1)                                                    0068000
     69* C                                                                           0069000
     70* C                    VERTICAL ADVECTION FOR TANGENTIAL VELOCITY             0070000
     71* C                                                                           0071000
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CARD IMAGE FILE EDITOR(CIFED) -- VERSION 05.29  DATE=10/26/82       TIME=16:12:12:99

*** MEMBER ADVECT

            72*        DO 100 J=2,N2                                                          0072000
            73*        DO 100 I=2,M1                                                          0073000
            74*   100 VT3(I,J)=VT3(I,J)+0.25*((VZ(I-1,J)+VZ(I,J))*(VT(I,J)-VT(I,J-1))       0074000
            75*       1          /DZ2(J)+(VZ(I,J+1)+VZ(I-1,J+1))*(VT(I,J+1)-VT(I,J))       0075000
            76*       2          /DZ2(J+1))                                                 0076000
            77*        DO 105 I=2,M1                                                          0077000
            78*   105 VT3(I,1)=VT3(I,1)+0.25*(VZ(I,2)+VZ(I-1,2))*(VT(I,2)-VT(I,1))           0078000
            79*       1          /DZ2(2)                                                    0079000
            80*        DO 106 I=2,M1                                                          0080000
            81*   106 VT3(I,N1)=VT3(I,N1)+0.25*(VZ(I,N1)+VZ(I-1,N1))*(VT(I,N1)-VT(I,N2))  0081000
            82*       1          /DZ2(N1)                                                   0082000
            83* C                                                                           0083000
            84* C                    VERTICAL ADVECTION FOR VERTICAL VELOCITY               0084000
            85* C                                                                           0085000
            86*        DO 140 J=2,N1                                                          0086000
            87*        DO 140 I=1,M1                                                          0087000
            88*   140 VZ3(I,J)=VZ3(I,J)-0.25*((VZ(I,J-1)+VZ(I,J))*(VZ(I,J)-VZ(I,J-1))       0088000
            89*       1          /DZ1(J-1)+(VZ(I,J+1)+VZ(I,J))*(VZ(I,J+1)-VZ(I,J))         0089000
            90*       2          /DZ1(J))                                                   0090000
            91* C                                                                           0091000
            92* C                    VERTICAL ADVECTION FOR B                               0092000
            93* C                                                                           0093000
            94*        DO 150 J=2,N2                                                          0094000
            95*        DO 150 I=1,M1                                                          0095000
            96*   150 B3(I,J)=B3(I,J)-0.5*(VZ(I,J)*(B(I,J)-B(I,J-1))/DZ2(J)                  0096000
            97*       1          +VZ(I,J+1)*(B(I,J+1)-B(I,J))/DZ2(J+1))                     0097000
            98*        DO 160 I=1,M1                                                          0098000
            99*   160 B3(I,1)=B3(I,1)-0.5*VZ(I,2)*(B2(I,2)-B2(I,1))/DZ2(2)                   0099000
           100*        DO 170 I=1,M1                                                          0100000
           101*   170 B3(I,N1)=B3(I,N1)-0.5*VZ(I,N1)*(B(I,N1)-B(I,N2))/DZ2(N1)              0101000
           102* C                                                                           0102000
           103* C                    INERTIA TERMS FOR HORIZONTAL MOMENTUM                  0103000
           104* C                                                                           0104000
           105*        DO 110 J=1,N1                                                          0105000
           106*        DO 110 I=2,M1                                                          0106000
           107*        VR3(I,J)=VR3(I,J)+VT(I,J)*(VT(I,J)/R1(I)+C0RI)                         0107000
           108*   110 VT3(I,J)=VT3(I,J)-VR(I,J)*(VT(I,J)/R1(I)+C0RI)                         0108000
           109* C                                                                           0109000
           110* C                    BUOYANCY TERM FOR VERTICAL ACCELERATION                0110000
           111* C                                                                           0111000
           112*        DO 120 J=2,N1                                                          0112000
           113*        DO 120 I=1,M1                                                          0113000
           114*   120 VZ3(I,J)=VZ3(I,J)-0.5*(R(I,J)+B(I,J-1))                                0114000
           115* C                                                                           0115000
           116* C                    STRATIFICATION TERM                                    0116000
           117* C                                                                           0117000
           118*        DO 130 J=1,N1                                                          0118000
           119*        DO 130 I=1,M1                                                          0119000
           120*   130 B3(I,J)=B3(I,J)+0.5*(VZ(I,J)*BV2(J)+VZ(I,J+1)*BV2(J+1))              0120000
           121*        RETURN                                                                 0121000
           122*        END                                                                    0122000

*** MEMBER ADVECT   ADDED TO    SOURCE   --   122 RECORDS
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CARD IMAGE FILE EDITOR(CIFED) -- VERSION 05.29  DATE=10/26/82        TIME=14:12:12:99

*** MEMBER PLTOUT

      1*        SUBROUTINE PUTOUT                                                       0001000
      2*        PARAMETER M=21,N=21                                                     0002000
      3*        PARAMETER M1=M-1,M2=M-2,N1=N-1,N2=N-2                                   0003000
      4*        COMMON/ONE/VR1(M,N1),VT1(M,N1),VZ1(M-1,N),B1(M1,N1),VR2(M,N1),          0004000
      5*       1           VT2(M,N1),VZ2(M1,N),B2(M1,N1),VR3(M,N1),VT3(M,N1),         0005000
      6*       2           VZ3(M1,N),B3(M1,N1),P(M1,N1)                               0006000
      7*        COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N)      0007000
      8*        COMMON/THR/RHO,PHOR(N1),BV2(N),ALPHA,BNDA,BNDB,CORI,G,RK(M),ZK(N)       0008000
      9*        COMMON/FOR/DELT,XTIME,ITIME,ISTEP,ISMO,ITAPE,TBV                        0009000
     10* C                                                                             0010000
     11* C                    THIS SUBROUTINE PRINT OUT FIELDS FOR A QUICK LOOK         0011000
     12* C                                                                             0012000
     13*        DIMENSION IDUM(M,N)                                                     0013000
     14*   700 FORMAT(////,'  RADIAL VELOCITY (CM/S) AT T=',I6,' H')                    0014000
     15*   705 FORMAT(////,'  TANGENTIAL VELOCITY (CM/S) AT T=',I6,' H')               0015000
     16*   710 FORMAT(////,'  VERTICAL VELOCITY (CM/S) AT T=',I6,' H')                 0016000
     17*   715 FORMAT(////,'  BUOYANCY FIELD (*.001) AT T=',I6,' H')                   0017000
     18*   725 FORMAT(////,'  PRESSURE (*10 DYNE/CM**2) AT TIME=',I6,' H')             0018000
     19*   720 FORMAT(1H1,////,20X,'**********   OUTPUT AT TIME =',I6,' H    OR',     0019000
     20*      1 F8.2,' DAY     ISTEP =',I7,'    **************')                       0020000
     21*        DAY=TIME/86400.+.0001                                                   0021000
     22*        PRINT 720,ITIME,DAY,ISTEP                                               0022000
     23*        DO 10 J=1,N1                                                            0023000
     24*        DO 10 I=1,M                                                             0024000
     25*     10 IDUM(I,J)=VR2(I,J)                                                      0025000
     26*        PRINT 700,ITIME                                                         0026000
     27*        CALL MAP(IDUM,R1,Z2,M,N1)                                               0027000
     28*        DO 20 J=1,N1                                                            0028000
     29*        DO 20 I=1,M                                                             0029000
     30*     20 IDUM(I,J)=VT2(I,J)                                                      0030000
     31*        PRINT 705,ITIME                                                         0031000
     32*        CALL MAP(IDUM,R1,Z2,M,N1)                                               0032000
     33*        DO 30 J=1,N                                                             0033000
     34*        DO 30 I=1,M1                                                            0034000
     35*     30 IDUM(I,J)=VZ2(I,J)                                                      0035000
     36*        PRINT 710,ITIME                                                         0036000
     37*        CALL MAP(IDUM,R2,Z1,M1,N)                                               0037000
     38*        DO 40 J=1,N1                                                            0038000
     39*        DO 40 I=1,M1                                                            0039000
     40*     40 IDUM(I,J)=BR2(I,J)*1.E3                                                 0040000
     41*        PRINT 715,ITIME                                                         0041000
     42*        CALL MAP(IDUM,R2,Z2,M1,N1)                                              0042000
     43*        DO 50 J=1,N1                                                            0043000
     44*        DO 50 I=1,M1                                                            0044000
     45*     50 IDUM(I,J)=BP(I,J)*1.E-1                                                 0045000
     46*        PRINT 725,ITIME                                                         0046000
     47*        CALL MAP(IDUM,R2,Z2,M1,N1)                                              0047000
     48*        RETURN                                                                  0048000
     49*        END                                                                     0049000
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CARD IMAGE FILE EDITOR(CIPEN) -- VERSION 05.29  DATE=10/26/82       TIME=14:12:12:99

*** MEMBER MAP

                1*       SUBROUTINE MAP(A,M,Z,MM,NN)                                    0001000
                2*       PARAMETER MB21,NB21                                            0002000
                3*       DIMENSION R(MM),Z(NN)                                          0003000
                4*       INTEGER A (M,N),IR(M),IZ(N)                                    0004000
                5*    70 FORMAT(1HS,7X,25I5)                                            0005000
                6*    80 FORMAT(1HS,I4,3X,25I5)                                         0006000
                7*       MP=MINO(25,MM)                                                 0007000
                8*       DO 10 I=1,MP                                                   0008000
                9*    10 IR(I)=R(I)+1.E-5*R.1                                           0009000
               10*       DO 20 J=1,NN                                                   0010000
               11*    20 IZ(J)=Z(J)+1.E-6*0.1                                           0011000
               12*       PRINT 70                                                       0012000
               13*       PRINT 70,(IR(I),I=1,MP)                                        0013000
               14*       PRINT 70                                                       0014000
               15*       DO 30 JJ=1,NN                                                  0015000
               16*       J=NN+1-JJ                                                      0016000
               17*    30 PRINT 80,IZ(J),(A(I,J),I=1,MP)                                 0017000
               18*       RETURN                                                         0018000
               19*       END                                                            0019000
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CARD IMAGE FILE EDITOR(CIFED) -- VERSION 05.29  DATE=10/26/82       TIME=14:12:12:99

*** MEMBER PRESS

                1*        SUBROUTINE PRESS                                                      0001000
                2* C                                                                             0002000
                3* C                    THIS SUBROUTINE SETS UP FORCING FUNCTIONS AND BOUNDARY0003000
                4* C                    CONDITIONS FOR THE PRESSURE DIAGNOSTIC EQUATIONS FOR S0004000
                5* C                                                                             0005000
                6*        PARAMETER M=21,N=21                                                   0006000
                7*        PARAMETER M1=M-1,M2=M-2,N1=N-1,N2=N-2                                 0007000
                8*        PARAMETER NBLK=2,NBLK1=NBLK-1                                         0008000
                9*        REAL*8 RCOR,RINV,RINV1,RTILDA,DUMMY1                                  0009000
               10*        COMMON/ONE/VR1(M,N1),VT1(M,N1),VZ1(M1,N),B1(M1,N1),VR2(M,N1),         0010000
               11*       1           VT2(M,N1),VZ2(M1,N),B2(M1,N1),VR3(M,N1),VT3(M,N1),         0011000
               12*       2           VZ3(M1,N),B3(M1,N1),P(M1,N1)                               0012000
               13*        COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N)    0013000
               14*        COMMON/THR/RHO,MACH(M1),BV2(N),ALPHA,BNDA,BNDR,CORI,G,RM(M),ZK(N)     0014000
               15* C                                                                             0015000
               16* C                     MP=NP IS THE SIZE OF X AND F                            0016000
               17* C                     MP=M+2,NP=N+NBLK+1                                      0017000
               18* C                                                                             0018000
               19*        PARAMETER MP=M+1,NP=N+1                                               0019000
               20*        PARAMETER MP1=MP-1,MP2=MP-2,NP1=NP-1,NP2=NP-2                         0020000
               21*        COMMON/EVP/RINV(MP2,MP2,NBLK),RINV1(MP2,MP2,NBLK1),RCOR(MP,3),        0021000
               22*       1           RTILLA(MP2),F(MP,NP),NBSIZ2(NBLK),IS(NBLK),JLMF(NBLK),     0022000
               23*       2           IE(NBLK),F11(MP),F1N(MP),F21(NP),F2M(NP),AX(MP),AY(NP),    0023000
               24*       3           PB(MP,NP),CX(MP),CY(NP)                                    0024000
               25*        DIMENSION DUMMY1(MP2,MP2),X(MP,NP)                                    0025000
               26*        EQUIVALENCE(DUMMY1,RINV(1,1,NBLK))                                    0026000
               27*        PARAMETER MPNP=MP*NP                                                  0027000
               28*        DATA DUMMY1/MPNP*0.0/,X/MPNP*0.0/                                     0028000
               29*        DATA NCALL/0/                                                         0029000
               30* C  NBSIZ2 REPRESENTS NUMBER OF INTERIOR GRID POINTS IN EACH BLOCK IN X-DI0030000
               31* C N2 REPRESENTS NUMBER OF INTERIOR GRID POINTS IN Y-DIRECTION             0031000
               32* C NBLK REPRESENTS NUMBER OF BLOCKS IN X-DIRECTION                        0032000
               33* C THE VARIABLES A11,A1N,A21,A2M TAKES THE VALUE 0 FOR DIRICHLET B.C.     0033000
               34* C  AND 1 FOR NEUMANN B.C.  AT THEIR RESPECTIVE BOUNDARIES  A11 CORRESPOND0034000
               35* C  J=1      A1N  TO J=N          A21   TO I=1      A2M   TO I=M           0035000
               36* C BOUNDARY CONDITIONS ARE                                                0036000
               37* C   X(I,1)=(1-A11)*X(I,1)+A11*(X(I,2)-F11(I))                            0037000
               38* C   X(I,NP)=(1-A1N)*X(I,NP)+A1N*(X(I,NP-1)-F1N(I))                      0038000
               39* C   X(1,J)=(1-A21)*X(1,J)+A21*(X(2,J)-F21(J))                           0039000
               40* C   X(MP,J)=(1-A2M)*X(MP,J)+A2M*(X(MP-1,J)-F2M(J))                     0040000
               41*        NCALL=NCALL+1                                                      0041000
               42* C                                                                       0042000
               43* C                     DEFINE THE FORCING FUNCTION OF THE ELLIPTIC EQUATION 0043000
               44* C                                                                       0044000
               45*        DO 10 J=1,NP2                                                    0045000
               46*        DO 10 I=1,MP2                                                    0046000
               47*     10 F(I+1,J+1)=(CX(I+1)*DR2(I+1)*VR3(I+1,J)+VZ3(I,J+1)/DZ1(J)        0047000
               48*       1           -AX(I+1)*DR2(I)*VR3(I,J)-VZ3(I,J)/DZ1(J))*RHO         0048000
               49* C                                                                       0049000
               50* C                     SET UP AN INITIAL GUESS                           0050000
               51* C                                                                       0051000
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*** MEMBER PRESS

                52*       IF(NCALL.GT.1)GO TO 30                                                0052000
                53*       DO 20 J=1,MP2                                                         0053000
                54*       DO 20 I=1,MP2                                                         0054000
                55*    20 X(I+1,J+1)=P(I,J)                                                     0055000
                56*    30 CONTINUE                                                              0056000
                57*       CALL ZILCH(F11,MP)                                                    0057000
                58*       CALL ZILCH(F1N,MP)                                                    0058000
                59*       CALL ZILCH(F21,MP)                                                    0059000
                60* C                                                                           0060000
                61* C                    DEFINE THE FORCING AT BOUNDARY SO THAT THERE          0061000
                62* C                    IS GRADIENT BALANCE AT OUTER BOUNDARY                 0062000
                63* C                                                                           0063000
                64*       DO 605 J=2,MP1                                                        0064000
                65*       F2M(J)=RHO*DR2(M)*VT2(M,J+1)*(VT2(M,J+1)/R1(M)+COR1)                  0065000
                66*   605 CONTINUE                                                             0066000
                67*       A11=1                                                                 0067000
                68*       A1N=1                                                                 0068000
                69*       A21=1                                                                 0069000
                70*       A2M=1                                                                 0070000
                71*       DO 101  J=2,MP1                                                       0071000
                72*       BB(2,J)=BB(2,J)+AX(2)*A21                                             0072000
                73*       F(2,J)=F(2,J)+AX(2)*F21(J)*A21                                        0073000
                74*       X(1,J)=(1.0-A21)*X(1,J)                                               0074000
                75*       BB(MP-1,J)=BB(MP-1,J)+CX(MP-1)*A2M                                    0075000
                76*       F(MP-1,J)=F(MP-1,J)-CX(MP-1)*F2M(J)*A2M                               0076000
                77*       X(MP,J)=(1.0-A2M)*X(MP,J)                                             0077000
                78*   101 CONTINUE                                                             0078000
                79*       DO 102 I=2,MP1                                                        0079000
                80*       BB(I,2)=BB(I,2)+AY(2)*A11                                             0080000
                81*       F(I,2)=F(I,2)+AY(2)*F11(I)*A11                                        0081000
                82*       X(I,1)=(1.0-A11)*X(I,1)                                               0082000
                83*       BB(I,MP-1)=BB(I,MP-1)+CY(MP-1)*A1N                                    0083000
                84*       F(I,MP-1)=F(I,MP-1)-CY(MP-1)*F1N(I)*A1N                               0084000
                85*       X(I,MP)=(1.0-A11)*X(I,MP)                                             0085000
                86*   102 CONTINUE                                                             0086000
                87*       IF(NCALL.EQ.1)CALL BSP1                                               0087000
                88*       ERROR=1.E-3                                                           0088000
                89*       CALL BSP2(X,ERROR,A11,A1N,A21,A2M)                                    0089000
                90* C                                                                           0090000
                91* C                    DEFINE THE DIAGNOSED PRESSURE                         0091000
                92* C                                                                           0092000
                93*       DO 110 J=1,M1                                                         0093000
                94*       DO 110 I=1,M1                                                         0094000
                95*   110 P(I,J)=X(I+1,J+1)                                                     0095000
                96*   115 CONTINUE                                                             0096000
                97* C                                                                           0097000
                98* C                    ADD PRESSURE GRADIENT FORCES TO VR3 AND VZ3            0098000
                99* C                                                                           0099000
               100*       DO 120 J=1,M1                                                         0100000
               101*       DO 120 I=2,M1                                                         0101000
               102*   120 VR3(I,J)=VR3(I,J)-(P(I,J)-P(I-1,J))/(RHO*DR2(I))                      0102000
               103*       DO 130 J=2,M1                                                         0103000
               104*       DO 130 I=1,M1                                                         0104000
               105*   130 VZ3(I,J)=VZ3(I,J)-(P(I,J)-P(I,J-1))/(RHO*DZ2(J))                      0105000
               106*       RETURN                                                                0106000
               107*       END                                                                   0107000
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*** MEMBER BSM1

                1*        SUBROUTINE BSM1                                                                0001000
                2*        PARAMETER M=21,N=21                                                            0002000
                3*        PARAMETER M1=M-1,M2=M-2,N1=N-1,N2=N-2                                          0003000
                4*        PARAMETER MP=M+1,NP=N+1                                                        0004000
                5*        PARAMETER MP1=MP-1,MP2=MP-2,NP1=NP-1,NP2=NP-2                                  0005000
                6*        PARAMETER NBLK=2,NBLK1=NBLK-1                                                  0006000
                7*        REAL*8 RCOR,RINV,RINV1,RTILDA,DUMMY1                                           0007000
                8*        COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N)             0008000
                9*        COMMON/EVP/RINV(MP2,MP2,NBLK),RINV1(MP2,MP2,NBLK1),RCOR(MP,3),                0009000
               10*       1            RTILDA(MP2),F(MP,NP),NBSIZ2(NBLK),IS(NBLK),SL=P(NBLK),           0010000
               11*       2            IE(NBLK),F11(MP),F1N(MP),F21(NP),F2M(NP),AX(MP),AY(NP),          0011000
               12*       3            BB(MP,NP),CX(MP),CY(NP)                                          0012000
               13*        DIMENSION DUMMY1(MP2,MP2)                                                      0013000
               14*        EQUIVALENCE (DUMMY1,RINV(1,1,NBLK))                                            0014000
               15*        IE(1)=NBSIZ2(1)+2                                                              0015000
               16*        DO 90 NB=2,NBLK                                                                0016000
               17*        IE(NB)=IE(NB-1)+NBSIZ2(NB)+1                                                   0017000
               18*   90 CONTINUE                                                                         0018000
               19*        DO 95 NB=1,NBLK1                                                               0019000
               20*        IS(NB+1)=IE(NB)-1                                                              0020000
               21*   95 CONTINUE                                                                         0021000
               22*        IS(1)=1                                                                        0022000
               23*        DO 115 II=1,MP2                                                                0023000
               24*        DO 110 J=1,3                                                                   0024000
               25*        DO 110 I=1,MP                                                                  0025000
               26*        RCOR(I,J)=0.0                                                                  0026000
               27*  110 CONTINUE                                                                         0027000
               28*        RCOR(II+1,2)=1.0                                                               0028000
               29*        NRS=IE(1)-1                                                                    0029000
               30*        DO 130 J1=2,NRS                                                                0030000
               31*        DO 135 I=2,MP1                                                                 0031000
               32*        RCOR(I,3)=(-AX(I)*RCOR(I-1,2)-AY(J1)*RCOR(I,1)-BB(I,J1)*                       0032000
               33*       1RCOR(I,2)-CX(I)*RCOR(I+1,2))/CY(J1)                                            0033000
               34*  135 CONTINUE                                                                         0034000
               35*        DO 140 I=1,MP                                                                  0035000
               36*        RCOR(I,1)=RCOR(I,2)                                                            0036000
               37*        RCOR(I,2)=RCOR(I,3)                                                            0037000
               38*  140 CONTINUE                                                                         0038000
               39*  130 CONTINUE                                                                         0039000
               40*        DO 145 I=1,MP2                                                                 0040000
               41*        RINV(II,I,1)=RCOR(I+1,1)                                                       0041000
               42*        DUMMY1(II,I)=RCOR(I+1,2)                                                       0042000
               43*  145 CONTINUE                                                                         0043000
               44*  115 CONTINUE                                                                         0044000
               45*        CALL MATINV(DUMMY1)                                                            0045000
               46*        DO 160 I=1,MP2                                                                 0046000
               47*        DO 160 J=1,MP2                                                                 0047000
               48*        RINV1(I,J,1)=0.0                                                               0048000
               49*        DO 161 K=1,MP2                                                                 0049000
               50*        RINV1(I,J,1)=RINV1(I,J,1)+DUMMY1(I,K)*RINV(K,J,1)                              0050000
               51*  161 CONTINUE                                                                         0051000
               52*  160 CONTINUE                                                                         0052000
               53*        DO 170 I=1,MP2                                                                 0053000
               54*        DO 170 J=1,MP2                                                                 0054000
               55*        RINV(I,J,1)=DUMMY1(I,J)                                                        0055000
               56*  170 CONTINUE                                                                         0056000
               57*        DO 205 NB=2,NBLK                                                               0057000
               58*        DO 215 II=1,MP2                                                                0058000
               59*        DO 210 J=1,3                                                                   0059000
               60*        DO 210 I=1,MP                                                                  0060000
               61*        RCOR(I,J)=0.0                                                                  0061000
               62*  210 CONTINUE                                                                         0062000
               63*        DO 220 I=1,MP2                                                                 0063000
               64*        RCOR(I+1,1)=RINV1(II,I,NB-1)                                                   0064000
               65*  220 CONTINUE                                                                         0065000
               66*        RCOR(II+1,2)=1.0                                                               0066000
               67*        IE1=IE(NB-1)                                                                   0067000
               68*       -IE2=IE(NB)-1                                                                   0068000
               69*        IF(NB.LT.NBLK) GO TO 232                                                       0069000
               70*        IE2=IE2-1                                                                      0070000
               71*  232 CONTINUE                                                                         0071000
               72*        DO 230 J1=IE1,IE2                                                              0072000
               73*        DO 235 I=2,MP1                                                                 0073000
               74*        RCOR(I,3)=(-AX(I)*RCOR(I-1,2)-AY(J1)*RCOR(I,1)-BB(I,J1)*                       0074000
               75*       1RCOR(I,2)-CX(I)*RCOR(I+1,2))/CY(J1)                                            0075000
               76*  235 CONTINUE                                                                         0076000
               77*        DO 240 I=1,MP
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*** MEMBER BSM1

                78*       RCBR(I,1)=RCBR(I,2)                                                    0077000
                79*       RCBR(I,2)=RCBR(I,3)                                                    0078000
                80*   270 CONTINUE                                                               0079000
                81*   241 CONTINUE                                                               0080000
                82*   230 CONTINUE                                                               0081000
                83*       IF(NB.EQ.NBLK) GO TO 246                                               0082000
                84*       DO 245 I=1,MP2                                                         0083000
                85*       RINV(II,I,NB)=R(DR(I+1,1)                                              0084000
                86*   245 CONTINUE                                                               0085000
                87*       DO 247 I=1,MP2                                                         0086000
                88*       DUMMY1(II,I)=RCBR(I+1,2)                                               0087000
                89*   247 CONTINUE                                                               0088000
                90*       GO TO 249                                                              0089000
                91*   246 CONTINUE                                                               0090000
                92*       DO 248 I=2,MP1                                                         0091000
                93*       DUMMY1(II,I-1)=AX(I)*RCBR(I-1,2)+AY(NP-1)*RCBR(I,1)+                   0092000
                94*      1RR(I,NP-1)*RCBR(I,2)+CX(I)*RCBR(I+1,2)                                 0093000
                95*   248 CONTINUE                                                               0094000
                96*   249 CONTINUE                                                               0095000
                97*   215 CONTINUE                                                               0096000
                98*       CALL MATINV(DUMMY1)                                                    0097000
                99*       IF(NB.EQ.NBLK) GO TO 275                                               0098000
               100*       DO 260 J=1,MP2                                                         0099000
               101*       DO 260 I=1,MP2                                                         0100000
               102*       RINV1(I,J,NB)=0.0                                                      0101000
               103*       DO 261 K=1,MP2                                                         0102000
               104*       RINV1(I,J,NB)=RINV1(I,J,NB)+DUMMY1(I,K)*RINV(K,J,NB)                   0103000
               105*   261 CONTINUE                                                               0104000
               106*   260 CONTINUE                                                               0105000
               107*       DO 270 J=1,MP2                                                         0106000
               108*       DO 270 I=1,MP2                                                         0107000
               109*       RINV(I,J,NB)=DUMMY1(I,J)                                               0108000
               110*   270 CONTINUE                                                               0109000
               111*   275 CONTINUE                                                               0110000
               112*   235 CONTINUE                                                               0111000
               113*       RETURN                                                                 0112000
               114*       END                                                                    0113000
                                                                                                 0114000
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CARD IMAGE FILE EDITOR(CIFED) -- VERSION 05.29 DATE=10/26/82 TIME=10:12:12.99

*** MEMBER MATINV

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      1*       SUBROUTINE MATINV(B)                                          0001000
      2*       PARAMETER MB=1                                                0002000
      3*       PARAMETER MP=MB+1                                             0003000
      4*       REAL*8 B(MP,MP)                                               0004000
      5*       REAL*8 B1(MP),B2(MP)                                          0005000
      6*       MP1=MP+1                                                      0006000
      7*       DO 110 I=1,MP1                                                0007000
      8*       B1(1)=1.0/B(I,I)                                              0008000
      9*       B(I,I)=1.0                                                    0009000
     10*       DO 112 J=1,MP                                                 0010000
     11*       B(I,J)=B(I,J)*B1(1)                                           0011000
     12*   112 CONTINUE                                                      0012000
     13*       IP1=I+1                                                       0013000
     14*       DO 120 I1=IP1,MP                                              0014000
     15*       B1(1)=B(I1,I)                                                 0015000
     16*   120 CONTINUE                                                      0016000
     17*       DO 125 I1=IP1,MP                                              0017000
     18*       B(I1,I)=0.0                                                   0018000
     19*   125 CONTINUE                                                      0019000
     20*       DO 127 J=1,MP                                                 0020000
     21*       B2(J)=B(I,J)                                                  0021000
     22*   127 CONTINUE                                                      0022000
     23*       DO 135 I1=IP1,MP                                              0023000
     24*       DO 135 J=1,MP                                                 0024000
     25*       B(I1,J)=B(I1,J)-B1(I1)*B2(J)                                  0025000
     26*   135 CONTINUE                                                      0026000
     27*   110 CONTINUE                                                      0027000
     28*       B1(1)=1.0/B(MP,MP)                                            0028000
     29*       B(MP,MP)=1.0                                                  0029000
     30*       DO 140 J=1,MP                                                 0030000
     31*       B(MP,J)=B(MP,J)*B1(1)                                         0031000
     32*   140 CONTINUE                                                      0032000
     33*       DO 150 I=2,MP                                                 0033000
     34*       DO 155 I2=1,I                                                 0034000
     35*       B1(I2)=B(I2,I)                                                0035000
     36*   155 CONTINUE                                                      0036000
     37*       IM1=I-1                                                       0037000
     38*       DO 156 I2=1,IM1                                               0038000
     39*       B(I2,I)=0.0                                                   0039000
     40*   156 CONTINUE                                                      0040000
     41*       DO 157 J=1,MP                                                 0041000
     42*       B2(J)=B(I,J)                                                  0042000
     43*   157 CONTINUE                                                      0043000
     44*       IM1=I-1                                                       0044000
     45*       DO 160 I2=1,IM1                                               0045000
     46*       DO 160 J=1,MP                                                 0046000
     47*       B(I2,J)=B(I2,J)-B1(I2)*B2(J)                                  0047000
     48*   160 CONTINUE                                                      0048000
     49*   150 CONTINUE                                                      0049000
     50*       RETURN                                                        0050000
     51*       END                                                           0051000
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CARD IMAGE FILE EDITOR(CIFEM) -- VERSION 05.29  DATE=10/26/82        TIME=14:12:12:99

*** MEMBER BSM2

                SUBROUTINE BSM2(X,FMMOR,A11,A1N,A21,A2N)                                0001000
                PARAMETER MB=21,NB=21                                                   0002000
                PARAMETER NBLK=2,NBL=1=NBLK=1                                           0003000
                PARAMETER MP=M+1,NP=N+1                                                 0004000
                PARAMETER MP1=MP-1,MP2=MP-2,NP1=NP-1,NP2=NP-2                           0005000
                REAL*8 RCOR,RINV,RINV1,RTILDA                                           0006000
                COMMON/EVP/RINV(MP2,MP2,NBLK),RINV1(MP2,MP2,NBLK-1),RCOR(MP,3),         0007000
               1           RTILDA(MP2),F(MP,NP),NBSIZ2(NBLK),IS(NBLK),SUMF(NBLK),       0008000
               2           IE(NBLK),F11(MP),F1N(MP),F21(NP),F2N(NP),AX(MP),AY(NP),      0009000
               3           BB(MB,NB),CX(MP),CY(NP)                                      0010000
                DIMENSION X(MP,NP)                                                      0011000
                DO 90 NB=1,NBLK                                                         0012000
                SUMF(NB)=0.0                                                            0013000
             90 CONTINUE                                                                0014000
                DO 95 NB=1,NBLK                                                         0015000
                DO 95 I=2,MP1                                                           0016000
                SUMF(NB)=SUMF(NB)+ABS(F(I,IE(NB)-1))                                    0017000
             95 CONTINUE                                                                0018000
                DO 96 NB=1,NBLK                                                         0019000
                IF(SUMF(NB).GT.0.0) GO TO 96                                            0020000
                SUMF(NB)=1.0                                                            0021000
             96 CONTINUE                                                                0022000
                NSTART=1                                                                0023000
                DO 199 IT=1,5                                                           0024000
                DO 200 NB=NSTART,NBLK                                                   0025000
                ISP1=IS(NB)+1                                                           0026000
                IEM2=IE(NB)-2                                                           0027000
                DO 205 J=ISP1,IEM2                                                      0028000
                DO 205 I=2,MP1                                                          0029000
                X(I,J+1)=(F(I,J)-AX(I)*X(I-1,J)-AY(J)*X(I,J-1)-BB(I,J)*                 0030000
               1X(I,J)-CX(I)*X(I+1,J))/CY(J)                                            0031000
            205 CONTINUE                                                                0032000
                IF(NB.EQ.NBLK) GO TO 200                                                0033000
                DO 522 IT=1,10                                                          0034000
                J1=IE(NB)-1                                                             0035000
                DO 215 I=2,MP1                                                          0036000
                RTILDA(I-1)=X(I,J1+1)-(F(I,J1)-AX(I)*X(I-1,J1)-AY(J1)*                  0037000
               1X(I,J1-1)-BB(I,J1)*X(I,J1)          -CX(I)*X(I+1,J1))/CY(J1)            0038000
            215 CONTINUE                                                                0039000
                A2=0.0                                                                  0040000
                DO 216 I=1,MP2                                                          0041000
                A2=A2+DABS(RTILDA(I))                                                   0042000
            216 CONTINUE                                                                0043000
                A3=A2/SUMF(NB)                                                          0044000
                IF(A3.LE.0.1) GO TO 230                                                 0045000
                DO 217 J=1,3                                                            0046000
                DO 217 I=1,MP                                                           0047000
                RCOR(I,J)=0.0                                                           0048000
            217 CONTINUE                                                                0049000
                DO 223 J=1,MP2                                                          0050000
                RCOR(J+1,2)=0.0                                                         0051000
                DO 223 J1=1,MP2                                                         0052000
                RCOR(J+1,2)=RCOR(J+1,2)+RTILDA(J1)*RINV(J1,J,NB)                        0053000
            223 CONTINUE                                                                0054000
                IF(NB.EQ.1) GO TO 251                                                   0055000
                DO 225 J=2,MP1                                                          0056000
                RCOR(J,1)=0.0                                                           0057000
                DO 225 K=2,MP1                                                          0058000
                RCOR(J,1)=RCOR(J,1)          +RCOR(K,2)*RINV1(K-1,J-1,NB-1)             0059000
            225 CONTINUE                                                                0060000
                DO 226 I=2,MP1                                                          0061000
                X(I,IS(NB))=X(I,IS(NB))+RCOR(I,1)                                       0062000
            226 CONTINUE                                                                0063000
            251 CONTINUE                                                                0064000
                CALL BSM3(X,IS(NB),IE(NB))                                              0065000
            522 CONTINUE                                                                0066000
            230 CONTINUE                                                                0067000
                J1=IE(NB)-1                                                             0068000
                DO 220 I=2,MP1                                                          0069000
                X(I,J1+1)=(F(I,J1)-AX(I)*X(I-1,J1)-AY(J1)*X(I,J1-1)-                    0070000
               1BB(I,J1)*X(I,J1)-CX(I)*X(I+1,J1))/CY(J1)                                0071000
            220 CONTINUE                                                                0072000
            501 CONTINUE                                                                0073000
            200 CONTINUE                                                                0074000
                DO 300 NB=1,NBLK                                                        0075000
                NB=NBLK-NB+1                                                            0076000
                ISP1=IS(NB)+1                                                           0077000
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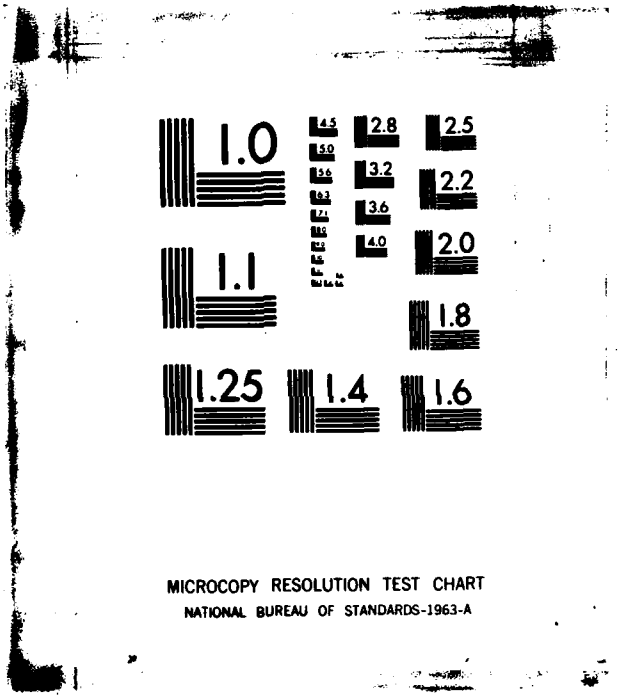
*** MEMBER BSM2

                78*       IEM2=IE(NB)-2                                                  0078000
                79*       J=IEM2                                                         0079000
                80*       IF(NB.EQ.NBLK) GO TO 502                                       0080000
                81*       DO 305 I=2,MP1                                                 0081000
                82*       X(I,J+1)=(F(I,J)-AX(I)*X(I-1,J)-AY(J)*X(I,J-1)-BB(I,J)*        0082000
                83*      1X(I,J)-CX(I)*X(I+1,J))/CY(J)                                   0083000
                84*   305 CONTINUE                                                       0084000
                85*   502 CONTINUE                                                       0085000
                86*       DO 552 IT=1,10                                                 0086000
                87*       IF(NB.EQ.NBLK) GO TO 317                                       0087000
                88*       J1=IE(NB)-1                                                    0088000
                89*       DO 315 I=2,MP1                                                 0089000
                90*       RTILDA(I-1)=X(I,J1+1)-(F(I,J1)-AX(I)*X(I-1,J1)-AY(J1)*         0090000
                91*      1X(I,J1-1)-BB(I,J1)*X(I,J1)-CX(I)*X(I+1,J1))/CY(J1)             0091000
                92*   315 CONTINUE                                                       0092000
                93*       GO TO 318                                                      0093000
                94*   317 CONTINUE                                                       0094000
                95*       DO 319 I=2,MP1                                                 0095000
                96*       RTILDA(I-1)=F(I,NP-1)-(AX(I)*X(I-1,NP-1)+AY(NP-1)*X(I,NP-2)+   0096000
                97*      1BB(I,NP-1)*X(I,NP-1)+CX(I)*X(I+1,NP-1))                        0097000
                98*   319 CONTINUE                                                       0098000
                99*   318 CONTINUE                                                       0099000
               100*       A2=0.0                                                         0100000
               101*       DO 316 I=1,MP2                                                 0101000
               102*       A2=A2+DABS(RTILLA(I   ))                                       0102000
               103*   316 CONTINUE                                                       0103000
               104*       A3=A2/SUMF(NB)                                                 0104000
               105*       IF(A3.LE.ERROR) GO TO 300                                      0105000
               106*       DO 320 J=1,3                                                   0106000
               107*       DO 320 I=1,MP                                                  0107000
               108*       RCOR(I,J)=0.0                                                  0108000
               109*   320 CONTINUE                                                       0109000
               110*       DO 324 J=1,MP2                                                 0110000
               111*       RCOR(J+1,2)=0.0                                                0111000
               112*       DO 324 J1=1,MP2                                                0112000
               113*       RCOR(J+1,2)=RCOR(J+1,2)+RTILDA(J1)*RINV(J1,J,NB)               0113000
               114*   324 CONTINUE                                                       0114000
               115*       IF(NB.EQ.1) GO TO 551                                          0115000
               116*       DO 325 J=2,MP1                                                 0116000
               117*       RCOR(J,1)=0.0                                                  0117000
               118*       DO 325 K=2,MP1                                                 0118000
               119*       RCOR(J,1)=RCOR(J,1)          +RCOR(K,2)*RINV1(K-1,J-1,NR-1)    0119000
               120*   325 CONTINUE                                                       0120000
               121*       DO 326 I=2,MP1                                                 0121000
               122*       X(I,IS(NB))=X(I,IS(NB))+RCOR(I,1)                              0122000
               123*   326 CONTINUE                                                       0123000
               124*   551 CONTINUE                                                       0124000
               125*       CALL BSM3(X,IS(NB),IE(NB))                                     0125000
               126*   552 CONTINUE                                                       0126000
               127*   300 CONTINUE                                                       0127000
               128*       J1=IE(1)                                                       0128000
               129*       DO 330 I=2,MP1                                                 0129000
               130*       RTILDA(I-1)=X(I,J1+1)-(F(I,J1)-AX(I)*X(I-1,J1)-AY(J1)*         0130000
               131*      1X(I,J1-1)-BB(I,J1)*X(I,J1)          -CX(I)*X(I+1,J1))/CY(J1)   0131000
               132*   330 CONTINUE                                                       0132000
               133*       A2=0.0                                                         0133000
               134*       DO 332 I=1,MP2                                                 0134000
               135*       A2=A2+DABS(RTILLA(I))                                          0135000
               136*   332 CONTINUE                                                       0136000
               137*       A3=A2/SUMF(1)                                                  0137000
               138*       IF(A3.LE.ERROR) GO TO 201                                      0138000
               139*       NSTART=2                                                       0139000
               140*   199 CONTINUE                                                       0140000
               141*   201 CONTINUE                                                       0141000
               142*       DO 350 J=2,MP1                                                 0142000
               143*       X(1,J)=(1.0-A21)*X(1,J)+A21*(X(2,J)-F21(J))                    0143000
               144*       X(MP,J)=(1.0-A2M)*X(MP,J)+A2M*(X(MP-1,J)+F2M(J))               0144000
               145*   350 CONTINUE                                                       0145000
               146*       DO 360 I=2,MP1                                                 0146000
               147*       X(I,1)=(1.0-A11)*X(I,1)+A11*(X(I,2)-F11(I))                    0147000
               148*       X(I,NP)=(1.0-A1N)*X(I,NP)+A1N*(X(I,NP-1)+F1N(I))               0148000
               149*   360 CONTINUE                                                       0149000
               150*       DO 371 J=2,MP1                                                 0150000
               151*       BB(2,J)=BB(2,J)-AX(2)*A21                                      0151000
               152*       F(2,J)=F(2,J)-AX(2)*F21(J)*A21                                 0152000
               153*       BB(MP-1,J)=BB(MP-1,J)-CX(MP-1)*A2M                             0153000
```

AD-A137 421 TROPICAL WEATHER SYSTEM AND OCEAN MODELING(U) SCIENCE 2/2
APPLICATIONS INC MCLEAN VA S CHANG 1983 SAI-83-1155
N00014-82-C-2306

UNCLASSIFIED F/G 4/2 NL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1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3
7.1
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

CARD IMAGE FILE EDITOR(CIFEM) -- VERSION 05.29 DATE=10/26/82 TIME=14:12:12:19

*** MEMBER US*2

```
      F(MP-1,J)=F(MP-1,J)+CX(MP-1)*F2M(J)*A2M
  371 CONTINUE
      DO 372 I=2,MP1
      BB(I,2)=BB(I,2)-AY(2)*A11
      F(I,2)=F(I,2)-AY(2)*F11(I)*A11
      BB(I,NP-1)=BB(I,NP-1)-CY(NP-1)*A1N
      F(I,NP-1)=F(I,NP-1)+CY(NP-1)*F1N(I)*A1N
  372 CONTINUE
      RETURN
      END
```

```
CARD IMAGE FILE ECITOP(CIFEN) -- VERSION 05.29  DATE=10/26/82       TIME=14:12:12:00

*** MEMBER= BSM3

      1*       SUBROUTINE BSM3(X,ISS,IEE)                                          0001000
      2*       PARAMETER MB21,NB21                                                 0002000
      3*       PARAMETER NBLK=2,NBLK1=NBLK-1                                       0003000
      4*       PARAMETER MP=M+1,NP=N+1                                             0004000
      5*       PARAMETER MP1=MP-1,MP2=MP-2,NP1=NP-1,NP2=NP-2                       0005000
      6*       REAL*8 RCOR,RINV,RINV1,RTILDA                                       0006000
      7*       DIMENSION X(MP,NP)                                                  0007000
      8*       COMMON/EVP/RINV(MP2,MP2,NBLK),RINV1(MP2,MP2,NBLK1),RCOR(MP,3),     0008000
      9*      1           RTILDA(MP2),F(MP,NP),NBSIZ2(NBLK),IS(NBLK),JLMP(NBLK),  0009000
     10*      2           IE(NBLK),F11(MP),F1N(MP),F21(NP),F2M(NP),AX(MP),AY(NP), 0010000
     11*      3           BB(MP,NP),CX(MP),CY(NP)                                 0011000
     12*       DO 135 I=2,MP1                                                      0012000
     13*       X(I,ISS+1)=X(I,ISS+1)+RCOR(I,2)                                     0013000
     14*  135  CONTINUE                                                            0014000
     15*       ISP1=ISS+1                                                          0015000
     16*       IEM2=IEE-2                                                          0016000
     17*       DO 140 J=ISP1,IEM2                                                  0017000
     18*       DO 145 I=2,MP1                                                      0018000
     19*       RCOR(I,3)=(-AX(I)*RCOR(I-1,2)-AY(J)*RCOR(I,1)-BB(I,J)*              0019000
     20*      1RCOR(I,2)-CX(I)*RCOR(I+1,2))/CY(J)                                  0020000
     21*  145  CONTINUE                                                            0021000
     22*       DO 150 I=2,MP1                                                      0022000
     23*       X(I,J+1)=X(I,J+1)+RCOR(I,3)                                         0023000
     24*       RCOR(I,1)=RCOR(I,2)                                                 0024000
     25*       RCOR(I,2)=RCOR(I,3)                                                 0025000
     26*  150  CONTINUE                                                            0026000
     27*  140  CONTINUE                                                            0027000
     28*       RETURN                                                              0028000
     29*       END                                                                 0029000
```

```
CARD IMAGE FILE EDITOR(CIFED) -- VERSION 05.20  DATE=10/20/82       TIME=14:11:32:36

<<SPLIT OCEAN1,SOURCE,PRINT,SEG

      1*        PROGRAM OCEAN                                                 0001000
      2*        PARAMETER M=21,N=21                                           0002000
      3*        PARAMETER M1=M-1,M2=M-2,N1=N-1,N2=N-2                         0003000
      4*        PARAMETER ND=2*M*N+1*M1*N1                                    0004000
      5*        DIMENSION DATA1(ND),DATA2(ND),DATA3(ND)                       0005000
      6*        COMMON/ONE/VR1(M,N1),VT1(M,N1),B1(M1,N1),VR2(M,N1),           0006000
      7*       1           VT2(M,N1),B2(M1,N1),VR3(M,N1),VT3(M,N1),           0007000
      8*       2           B3(M1,N1),P(M1,N1),VZ(M1,N)                        0008000
      9*        EQUIVALENCE (DATA1,VR1),(DATA2,VR2),(DATA3,VR3)               0009000
     10*        DATA DATA1/ND*0./,DATA2/ND*0./,DATA3/ND*0./                   0010000
     11*        COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N) 0011000
     12*        COMMON/THR/AMO,AMOR(N1),BV2(N),ALPHA,BNDA,BNDB,CORI,G,HM(M),ZK(N) 0012000
     13*        COMMON/FOR/DELT,XTIME,ITIME,ISTEP,ISMO,ITAPE,TBV              0013000
     14*        CALL INDUMP                                                   0014000
     15*    100 FORMAT(I6)                                                    0015000
     16*        READ(5,100)ITIME                                              0016000
     17*        READ(5,100)ITER                                               0017000
     18*        READ(5,100)IOUT                                               0018000
     19*        READ(5,100)ISMO                                               0019000
     20*        ISTEP=0                                                       0020000
     21*        READ(5,100)ITAPE                                              0021000
     22*        CALL INIT                                                     0022000
     23*        IF(ITIME.EQ.0)GO TO 10                                        0023000
     24* C                                                                   0024000
     25* C                    CONTINUED INTEGRATION FROM A HISTORY TAPE       0025000
     26* C                                                                   0026000
     27*        READ(1)ITIME,DATA1,DATA2,P                                    0027000
     28*        GO TO 20                                                      0028000
     29*     10 CALL START                                                    0029000
     30*     20 XTIME=ITIME+3006.                                             0030000
     31* C                                                                   0031000
     32* C                    PRINT OUT INITIAL FIELDS                       0032000
     33* C                                                                   0033000
     34*        CALL PUTOUT                                                   0034000
     35*        IF(ITER.EQ.0)STOP                                             0035000
     36*        DO 90 ISTEP=1,ITER                                            0036000
     37* C                                                                   0037000
     38* C                    COMPUTE HYDROSTATIC PRESSURE AND DIAGNOSE VERTICAL VE0038000
     39* C                                                                   0039000
     40*        CALL UP                                                       0040000
     41* C                                                                   0041000
     42* C                 COMPUTE ALL INVISCID TERMS                        0042000
     43* C                                                                   0043000
     44*        CALL ADVECT                                                   0044000
     45* C                                                                   0045000
     46* C                    COMPUTE VISCOUS TERMS                          0046000
     47* C                                                                   0047000
     48*        CALL DIFF                                                     0048000
     49* C                                                                   0049000
     50* C                    MARCHING IN TIME                               0050000
     51* C                    FIRST TIME STEP IS FORWARD IF START IS CALLED   0051000
     52* C                                                                   0052000
     53*        IF(ISTEP.EQ.1.AND.ITIME.EQ.0)DELT=0.5*DELT                    0053000
     54*        CALL FORWD                                                    0054000
     55*        IF(ISTEP.EQ.1.AND.ITIME.EQ.0)DELT=2.*DELT                     0055000
     56* C                                                                   0056000
     57* C                    DEFINE BOUNDARY VALUES FOR VELOCITY            0057000
     58* C                                                                   0058000
     59*        CALL BOUNDV                                                   0059000
     60* C                                                                   0060000
     61* C                    CHECK IF DELT IS STABLE                        0061000
     62* CC                                                                  0062000
     63*        CALL CHECK                                                    0063000
     64*        XTIME=XTIME+DELT                                              0064000
     65*        ITIME=XTIME/3006.                                             0065000
     66* C                                                                   0066000
     67* C                    PRINT OUT RESULTS EVERY IOUT STEPS             0067000
     68* C                                                                   0068000
     69*        IF(MOD(ISTEP,IOUT).EQ.0)CALL PUTOUT                           0069000
     70* C                                                                   0070000
     71* C                    WRITE HISTORY TAPE EVERY ITAPE STEPS           0071000
     72* C                                                                   0072000
     73*        IF(MOD(ISTEP,ITAPE).EQ.0)WRITE(2)ITIME,DATA1,DATA2,P          0073000
     74*     90 CONTINUE                                                     0074000
     75*        STOP                                                          0075000
     76*        END                                                           0076000
```

CARD IMAGE FILE EDITOR(CIFER) -- VERSION 05.2 DATE=10/26/82 TIME=14:16:32:36

*** MEMBER INIT

```
      SUBROUTINE  INIT                                                      0001000
      PARAMETER M=21,N=21                                                   0002000
      PARAMETER M1=M-1,M2=M-2,N1=N-1,N2=N-2                                 0003000
      COMMON/ONE/VR1(M,N1),VT1(M,N1),R1(M1,N1),VR2(M,N1),                   0004000
     1          VT2(M,N1),R2(M1,N1),VR3(M,N1),VT3(M,N1),                   0005000
     2          R3(M1,N1),P(M1,N1),VZ(M1,N)                                0006000
      COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N)    0007000
      COMMON/THR/RHO,RHOR(N1),RV2(N),ALPHA,RNDA,RNDB,CORI,G,HK(M),ZK(N)     0008000
      COMMON/FOR/DELT,XTIME,ITIME,ISTEP,ISME,ITAPE,TRV                      0009000
C                                                                           0010000
C                     INITIALIZE ALL DEPENDENT VARIABLES AND CONSTANTS      0011000
C                                                                           0012000
C                                                                           0013000
C                      ALPHA IS THE NONDIMENSIONAL SMOOTHING COEF.          0014000
C                      FOR TIME SMOOTHING IN SUBROUTINE FRWRD               0015000
C                                                                           0016000
      DELT=900.                                                             0017000
      ALPHA=0.10                                                            0018000
      RHO=0.                                                                0019000
      LAT=30                                                                0020000
      CORI=2.*7.2722E-5*SIN(LAT*3.14159/180.)                               0021000
C                                                                           0022000
C                     DEFINE RADII AT GRID POINTS AND ALL GRID INTERVALS    0023000
C                                                                           0024000
      DO 10 I=1,M1                                                          0025000
   10 DR1(I)=20.E5                                                          0026000
      R1(1)=0.                                                              0027000
      DO 20 I=2,M                                                           0028000
   20 R1(I)=R1(I-1)+DR1(I-1)                                                0029000
      DO 30 I=1,M1                                                          0030000
   30 R2(I)=0.5*(R1(I)+R1(I+1))                                             0031000
      DR2(1)=2.*(R2(1)-R1(1))                                               0032000
      DR2(M)=2.*(R1(M)-R2(M1))                                              0033000
      DO 40 I=2,M1                                                          0034000
   40 DR2(I)=R2(I)-R2(I-1)                                                  0035000
C     MAX=MAXMAG(DR1)                                                       0036000
C     DR=MAX=DP1(MAX)                                                       0037000
C                                                                           0038000
C                     DEFINE ALL DZ'S                                       0039000
C                                                                           0040000
      DO 100 J=1,N                                                          0041000
  100 Z1(J)=(J-1)*200.E2                                                    0042000
      DO 110 J=1,N1                                                         0043000
  110 DZ1(J)=Z1(J+1)-Z1(J)                                                  0044000
      DZ2(1)=2.*(0.5*DZ1(1)-Z1(1))                                          0045000
      Z2(1)=0.5*DZ2(1)                                                      0046000
      DO 120 J=2,N1                                                         0047000
      DZ2(J)=0.5*(DZ1(J)+DZ1(J-1))                                          0048000
  120 Z2(J)=Z2(J-1)+DZ2(J)                                                  0049000
      DZ2(N)=2.*(Z1(N)-Z1(N-1)-0.5*DZ1(N1))                                 0050000
C                                                                           0051000
C                     A AND B ARE CONSTANT USED IN SUBROUTINE BOUNDV        0052000
C                     FOR CONSTANT DIV. AND VORT. CONDITIONS                0053000
C                                                                           0054000
      RNDA=R1(M1)/R1(M)                                                     0055000
      RNDB=(R1(M1)+R1(M))*DR1(M1)/((R1(M1)+R1(M2))*R1(M)*DR1(M2))           0056000
      RNDB=0.                                                               0057000
C                                                                           0058000
C                     DEFINE DENSITY RELATED CONSTANTS                      0059000
C                                                                           0060000
      RHO=1.                                                                0061000
      DO 130 J=1,N                                                          0062000
  130 BV2(J)=1.E-6                                                          0063000
      TBV=0.                                                                0064000
      DO 135 J=1,N                                                          0065000
  135 TBV=AMAX1(TBV,BV2(J))                                                 0066000
      TBV=1./SQRT(TBV)                                                      0067000
C                                                                           0068000
C                     DEFINE HORIZONTAL AND VERTICAL DIFFUSION COEFFIENTS   0069000
C                                                                           0070000
      COEFH=0.002*DR1(1)**2/DELT                                            0071000
      COEFZ=0.001*DZ1(1)**2/DELT                                            0072000
      DO 140 I=1,M1                                                         0073000
  140 HK(I)=COEFH*(1.+5.*EXP(-FLOAT(M1-I)/7.))                              0074000
      DO 150 J=1,N1                                                         0075000
  150 ZK(J)=COEFZ*(1.+5.*(EXP(-FLOAT(J-1)/5.)+EXP(-FLOAT(N1-J)/5.)))        0076000
      RETURN                                                                0077000
      END                                                                   0078000
```

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CARD IMAGE FILE EDITOR(CIFE) -- VERSION 05.29  DATE=10/26/82       TIME=14:16:32:36

*** MEMBER START

                1*       SUBROUTINE START                                                        0001000
                2*       PARAMETER MB21,MB21                                                     0002000
                3*       PARAMETER M1=M=1,M2=M=2,N1=N=1,N2=N=2                                   0003000
                4*       COMMON/ONE/VR1(M,N1),VT1(M,N1),R1(M1,N1),VR2(M,N1),                     0004000
                5*      1          VT2(M,N1),B2(M1,N1),VR3(M,N1),VT3(M,N1),                     0005000
                6*      2          B3(M1,N1),P(M1,N1),VZ(M1,N)                                  0006000
                7*       COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N)      0007000
                8*       COMMON/TWR/RM0,RM0R(N1),BV2(N),ALPHA,BNDA,BNDB,CORI,G,MK(M),ZK(N)       0008000
                9*       PARAMETER ND=2*M*N1=N1                                                  0009000
               10*       DIMENSION DATA1(ND),DATA2(ND)                                           0010000
               11*       EQUIVALENCE (DATA1,VR1),(DATA2,VR2)                                     0011000
               12* C                                                                             0012000
               13* C                    INITIALIZE MASS FIELDS FOR A THEORETICAL RING             0013000
               14* C                                                                             0014000
               15*       I11=1                                                                   0015000
               16*       I12=13                                                                  0016000
               17*       I21=I12+1                                                               0017000
               18*       I22=M1                                                                  0018000
               19*       BMASS=.0002                                                             0019000
               20*       DO 10 I=I11,I12                                                         0020000
               21*    10 B1(I,N1)=BMASS*COS(FLOAT(I-I11)/8.*3.1415)*G/RM0                        0021000
               22*       DO 30 I=I21,I22                                                         0022000
               23*    30 B1(I,N1)=B1(I12,N1)*EXP(-FLOAT(I-I21+1)/4.)                             0023000
               24*       DO 40 J=1,N2                                                            0024000
               25*       FACT=EXP(FLOAT(J-N1)/9.)                                                0025000
               26*       DO 40 I=1,M1                                                            0026000
               27*    40 B1(I,J)=B1(I,N1)*FACT                                                   0027000
               28* C                                                                             0028000
               29* C                    PRESSURE IS OBTAINED HYDROSTATICALLY FROM BUOYANCY        0029000
               30* C                                                                             0030000
               31*       DO 90 I=1,M1                                                            0031000
               32*    50 P(I,1)=0.5*RM0*DZ2(1)*B1(I,1)                                           0032000
               33*       DO 60 J=2,N1                                                            0033000
               34*       DO 60 I=1,M1                                                            0034000
               35*    60 P(I,J)=P(I,J-1)+0.5*RM0*DZ2(J)*(B1(I,J)+B1(I,J-1))                      0035000
               36* C                                                                             0036000
               37* C                    TANGENTIAL VELOCITY IS AT GRADIENT BALANCE                0037000
               38* C                                                                             0038000
               39*       DO 70 J=1,N1                                                            0039000
               40*       DO 70 I=2,M1                                                            0040000
               41*       PGF=(P(I,J)-P(I-1,J))/(RM0*DR2(I))                                      0041000
               42*       RAD=(0.5*CORI*R1(I))**2+R1(I)*PGF                                       0042000
               43*       JJ=J                                                                    0043000
               44*       II=I                                                                    0044000
               45*       IF(RAD.LT.0.)GO TO 100                                                  0045000
               46*    70 VT1(I,J)=-0.5*CORI*R1(I)+SQRT(RAD)                                      0046000
               47* C                                                                             0047000
               48* C                    SET DATA2=DATA1 FOR LEAPFROG                             0048000
               49* C                                                                             0049000
               50*       DO 80 I=1,ND                                                            0050000
               51*    80 DATA2(I)=DATA1(I)                                                       0051000
               52*       CALL WRLNDV                                                             0052000
               53*       DO 90 I=1,ND                                                            0053000
               54*    90 DATA1(I)=DATA2(I)                                                       0054000
               55*       RETURN                                                                  0055000
               56*   100 PRINT 110,II,JJ,PGF,RAD                                                 0056000
               57*   110 FORMAT(' RADICAL IN SUBROUTINE START IS NEGATIVE AT (I,J)=',2I5,       0057000
               58*      1' PGF, RAD =',1P2E12.3)                                                 0058000
               59*       STOP                                                                    0059000
               60*       END                                                                     0060000
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CARD IMAGE FILE EDITOR(CIFER) -- VERSION 05.29  DATE=10/26/82      TIME=14:14:32:36

*** MEMBER UP

      1*       SUBROUTINE UP                                                          0001000
      2*       PARAMETER M=21,N=21                                                    0002000
      3*       PARAMETER M1=M-1,P2=M-2,N1=N-1,N2=N-2                                  0003000
      4*       COMMON/ONE/VR1(M,N1),VT1(M,N1),B1(M1,N1),VR2(M,N1),                    0004000
      5*      1           VT2(M,N1),B2(M1,N1),VR3(M,N1),VT3(M,N1),                    0005000
      6*      2           B3(M1,N1),P(M1,N1),VZ(M1,N)                                 0006000
      7*       COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N)     0007000
      8*       COMMON/THR/RHO,RHOR(N1),BV2(N),ALPHA,BNDA,BNDB,CORI,G,MK(M),ZK(N)      0008000
      9*       PARAMETER M1=M-1,N1=N-1                                                0009000
     10*       DATA VZ/MIN=0./                                                        0010000
     11* C                                                                           0011000
     12* C                    PRESSURE IS OBTAINED HYDROSTATICALLY FROM B             0012000
     13* C                                                                           0013000
     14*       DO 10 I=1,M1                                                           0014000
     15*    10 P(I,1)=0.5*RHO*DZ2(I)*B2(I,1)                                          0015000
     16*       DO 20 J=2,N1                                                           0016000
     17*       DO 20 I=1,M1                                                           0017000
     18*    20 P(I,J)=P(I,J-1)+0.5*RHO*DZ2(J)*(B2(I,J)+B2(I,J-1))                     0018000
     19* C                                                                           0019000
     20* C                    DIAGNOSE VERTICAL VELOCITY BY CONTINUITY EQUATION       0020000
     21* C                                                                           0021000
     22*       DO 30 J=2,N1                                                           0022000
     23*       DO 30 I=1,M1                                                           0023000
     24*    30 VZ(I,J)=VZ(I,J-1)+DZ1(J)*((R1(I+1)*VR2(I+1,J-1)-R1(I)*VR2(I,J-1))    0024000
     25*      1       /(DR1(I)+0.5*(R1(I+1)+R1(I)))                                 0025000
     26*       RETURN                                                                 0026000
     27*       END                                                                    0027000
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CARD IMAGE FILE EDITOR(CIFED) -- VERSION 05.29  DATE=10/20/82       TIME=16:16:32:36

*** MEMBER BOUNDV

      1*       SUBROUTINE BOUNDV                                                      0001000
      2*       PARAMETER M=21,N=21                                                    0002000
      3*       PARAMETER N1=M-1,N2=M-2,N1=N-1,N2=N-2                                  0003000
      4*       COMMON/ONE/VR1(M,N1),VT1(M,N1),B1(M1,N1),VR2(M,N1),                    0004000
      5*      1          VT2(M,N1),B2(M1,N1),VR3(M,N1),VT3(M,N1),                    0005000
      6*      2          B3(M1,N1),P(M1,N1),VZ(M1,N)                                 0006000
      7*       COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N)     0007000
      8*       COMMON/THR/RHO,RMER(N1),RV2(N),ALPHA,BNDA,BNDB,CORI,G,HW(M),ZK(N)      0008000
      9* C                                                                           0009000
     10* C                  LATERAL BOUNDARY FOR TANGENTIAL AND RADIAL VELOCITIES    0010000
     11* C                  ASSUMING CONTINUOUS VORTICITY AND DIVERGENCE              0011000
     12* C                                                                           0012000
     13*       DO 10 J=1,N1                                                          0013000
     14*       VR2(M,J)=BNDA*VR2(M1,J)+BNDB*(R1(M1)*VR2(M1,J)-R1(M2)*VR2(M2,J))      0014000
     15*    10 VT2(M,J)=BNDA*VT2(M1,J)+BNDB*(R1(M1)*VT2(M1,J)-R1(M2)*VT2(M2,J))      0015000
     16*       RETURN                                                                0016000
     17*       END                                                                   0017000
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CARD IMAGE FILE EDITOR(CIFER) -- VERSION 05.29  DATE=10/26/82       TIME=14:16:32:36

*** MEMBER DIFF

      1*       SUBROUTINE DIFF                                                        0001000
      2* C                                                                           0002000
      3* C                    COMPUTE THE DIFFUSION TERMS                            0003000
      4* C                                                                           0004000
      5*       PARAMETER MX=21,NX=21                                                  0005000
      6*       PARAMETER M1=M-1,M2=M-2,N1=N-1,N2=N-2                                  0006000
      7*       COMMON/ONE/VR1(M,N1),VT1(M,N1),B1(M1,N1),VR2(M,N1),                    0007000
      8*      1          VT2(M,N1),B2(M1,N1),VR3(M,N1),VT3(M,N1),                    0008000
      9*      2          B3(M1,N1),P(M1,N1),VZ(M1,N)                                 0009000
     10*       COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N)    0010000
     11*       COMMON/THR/RHO,RHOB(N1),BVZ(N),ALPHA,BNDA,BNDB,CORI,G,HK(M),ZK(N)     0011000
     12*       DIMENSION VR(M,N1),VT(M,N1),B(M1,N1)                                  0012000
     13*       EQUIVALENCE (VR,VR1),(VT,VT1),(B,B1)                                  0013000
     14* C                                                                           0014000
     15* C                    HORIZONTAL DIFFUSION OF RADIAL VELOCITY                0015000
     16* C                                                                           0016000
     17*       DO 10 J=1,N1                                                          0017000
     18*       DO 10 I=2,M1                                                          0018000
     19*    10 VR3(I,J)=VR3(I,J)+HK(I)*(((VR(I+1,J)-VR(I,J))/DR1(I)                  0019000
     20*      1       -(VR(I,J)-VR(I-1,J))/DR1(I-1))/DR2(I)-VR(I,J)/(R1(I)*R1(I)))  0020000
     21*      2         +0.5*((VR(I+1,J)-VR(I,J))/(DR1(I)*R2(I))                    0021000
     22*      3         +(VR(I,J)-VR(I-1,J))/(DR1(I-1)*R2(I-1))))                   0022000
     23* C                                                                           0023000
     24* C                    HORIZONTAL DIFFUSION OF TANGENTIAL VELOCITY            0024000
     25* C                                                                           0025000
     26*       DO 20 J=1,N1                                                          0026000
     27*       DO 20 I=2,M1                                                          0027000
     28*    20 VT3(I,J)=VT3(I,J)+HK(I)*(((VT(I+1,J)-VT(I,J))/DR1(I)                  0028000
     29*      1       -(VT(I,J)-VT(I-1,J))/DR1(I-1))/DR2(I)-VT(I,J)/(R1(I)*R1(I)))  0029000
     30*      2         +0.5*((VT(I+1,J)-VT(I,J))/(DR1(I)*R2(I))                    0030000
     31*      3         +(VT(I,J)-VT(I-1,J))/(DR1(I-1)*R2(I-1))))                   0031000
     32* C                                                                           0032000
     33* C                    HORIZONTAL DIFFUSION OF B                              0033000
     34* C                                                                           0034000
     35*       DO 60 J=1,N1                                                          0035000
     36*       DO 60 I=2,M2                                                          0036000
     37*    60 B3(I,J)=B3(I,J)+HK(I)*(((B(I+1,J)-B(I,J))/DR2(I+1)                    0037000
     38*      1       -(B(I,J)-B(I-1,J))/DR1(I)                                     0038000
     39*      2         +0.5*((B(I+1,J)-B(I,J))/(DR2(I+1)*R1(I+1))                  0039000
     40*      3         +(B(I,J)-B(I-1,J))/(DR2(I)*R1(I))))                         0040000
     41*       DO 70 J=1,N1                                                          0041000
     42*    70 B3(1,J)=B3(1,J)+HK(1)*((B(2,J)-B(1,J))/(DR2(2)*DR1(1))               0042000
     43*      1         +0.5*(B(2,J)-B(1,J))/(DR2(2)*R1(2)))                        0043000
     44*       DO 80 J=1,N1                                                          0044000
     45*    80 B3(M1,J)=B3(M1,J)+HK(M1)*((-B(M1,J)+B(M2,J))/(DR2(M1)*DR1(M1))       0045000
     46*      1       -(B(M1,J)-B(P2,J))/(DR2(M1)*R1(M1)))                          0046000
     47* C                                                                           0047000
     48* C                    VERTICAL DIFFUSION OF RADIAL VELOCITY                  0048000
     49* C                                                                           0049000
     50*       DO 90 J=2,N2                                                          0050000
     51*       DO 90 I=2,M1                                                          0051000
     52*    90 VR3(I,J)=VR3(I,J)+ZK(J)*((VR(I,J+1)-VR(I,J))/DZ2(J+1)                 0052000
     53*      1       -(VR(I,J)-VR(I,J-1))/DZ2(J))/DZ1(J)                           0053000
     54*       DO 100 I=2,M1                                                         0054000
     55*   100 VR3(I,1)=VR3(I,1)+ZK(1)*(VR(I,2)-VR(I,1))/(DZ2(2)*DZ1(1))            0055000
     56*       DO 110 I=2,M1                                                         0056000
     57*   110 VR3(I,N1)=VR3(I,N1)+ZK(N1)*(-VR(I,N1)+VR(I,N2))/(DZ2(N1)*DZ1(N1))    0057000
     58* C                                                                           0058000
     59* C                    VERTICAL DIFFUSION OF TANGENTIAL VELOCITY              0059000
     60* C                                                                           0060000
     61*       DO 120 J=2,N2                                                         0061000
     62*       DO 120 I=2,M1                                                         0062000
     63*   120 VT3(I,J)=VT3(I,J)+ZK(J)*((VT(I,J+1)-VT(I,J))/DZ2(J+1)                0063000
     64*      1       -(VT(I,J)-VT(I,J-1))/DZ2(J))/DZ1(J)                           0064000
     65*       DO 130 I=2,M1                                                         0065000
     66*   130 VT3(I,1)=VT3(I,1)+ZK(1)*(VT(I,2)-VT(I,1))/(DZ2(2)*DZ1(1))            0066000
     67*       DO 140 I=2,M1                                                         0067000
     68*   140 VT3(I,N1)=VT3(I,N1)+ZK(N1)*(-VT(I,N1)+VT(I,N2))/(DZ2(N1)*DZ1(N1))    0068000
     69*                                                                           0069000
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CARD IMAGE FILE EDITOR(CIFED) -- VERSION 05.29  DATE=10/26/82       TIME=10:16:32:36

*** MEMBER DIFF

                70* C                                                                   0070000
                71* C                    VERTICAL DIFFUSION OF B                        0071000
                72* C                                                                   0072000
                73*       DO 160 J=2,N2                                                 0073000
                74*       DO 160 I=1,M1                                                 0074000
                75*   160 B3(I,J)=B3(I,J)+ZK(J)*((B1(I,J+1)-B(I,J))/DZ2(J+1)            0075000
                76*      1          -(B(I,J)-B(I,J-1))/DZ2(J))/DZ1(J)                  0076000
                77*       DO 170 I=1,M1                                                 0077000
                78*   170 B3(I,1)=B3(I,1)+ZK(1)*(B(I,2)-B(I,1))/(DZ2(2)*DZ1(1))         0078000
                79*       DO 180 I=1,M1                                                 0079000
                80*   180 B3(I,N1)=B3(I,N1)+ZK(N1)*(-B(I,N1)+B(I,N2))/(DZ2(N1)*DZ1(N1)) 0080000
                81*       RETURN                                                        0081000
                82*       END                                                           0082000
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CARD IMAGE FILE EDITOR(CIPEM) -- VERSION 05.29  DATE=10/26/82       TIME=14:16:32:36

*** MEMBER FRWRD

                1*       SUBROUTINE FRWRC                                                        0001000
                2*       PARAMETER M=21,N=21                                                     0002000
                3*       PARAMETER M1=M-1,M2=M-2,N1=N-1,N2=N-2                                   0003000
                4*       PARAMETER ND=2*M*N-1+M-1-N1                                             0004000
                5*       COMMON/ONE/DATA1(ND),DATA2(ND),DATA3(ND),P(M1,N1),V2(M1,N)              0005000
                6*       COMMON/THR/RHO,RHOR(M1),BV2(N),ALPHA,BNDA,BNDB,CORI,G,HH(M),ZK(N)       0006000
                7*       COMMON/FOR/DELT,XTIME,ITIME,ISTEP,ISHO,ITAPE,TBV                        0007000
                8* C                                                                              0008000
                9* C                    REPLACE DATA3 WITH THE NEW VALUES                         0009000
               10* C                                                                              0010000
               11*       DO 10 I=1,ND                                                            0011000
               12*    10 DATA3(I)=DATA1(I)+2.*DELT*DATA3(I)                                      0012000
               13* C                                                                              0013000
               14* C                    TIME SMOOTHING                                            0014000
               15* C                                                                              0015000
               16*       IF(MOD(ISTEP,ISHO).NE.0)GO TO 30                                        0016000
               17*       DO 20 I=1,ND                                                            0017000
               18*    20 DATA2(I)=DATA2(I)+(DATA1(I)+DATA3(I)-2.*DATA2(I))*ALPHA              0018000
               19*    30 CONTINUE                                                                0019000
               20* C                                                                              0020000
               21* C                    FORWARD MARCHING                                          0021000
               22* C                                                                              0022000
               23*       DO 40 I=1,ND                                                            0023000
               24*    40 DATA1(I)=DATA2(I)                                                       0024000
               25*       DO 50 I=1,ND                                                            0025000
               26*    50 DATA2(I)=DATA3(I)                                                       0026000
               27* C                                                                              0027000
               28* C                     ZERO OUT DATA3 FOR NEXT STEP                             0028000
               29* C                                                                              0029000
               30*       DO 60 I=1,ND                                                            0030000
               31*    60 DATA3(I)=0.                                                             0031000
               32*       RETURN                                                                  0032000
               33*       END                                                                     0033000
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CARD IMAGE FILE EDITOR(CIFEH) -- VERSION 05.29  DATE=10/26/82       TIME=14116:32:36

*** MEMBER CHECK

                1*       SUBROUTINE CHECK                                                        0001000
                2*       PARAMETER MB21,NB21                                                     0002000
                3*       PARAMETER M1=M=1,M2=M=2,N1=N=1,N2=N=2                                   0003000
                4*       COMMON/ONE/VR1(M,N1),VT1(M,N1),B1(M1,N1),VR2(M,N1),                     0004000
                5*      1           VT2(M,N1),B2(M1,N1),VR3(M,N1),VT3(M,N1),                     0005000
                6*      2           B3(M1,N1),P(M1,N1),VZ(M1,N)                                  0006000
                7*       COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N)      0007000
                8*       COMMON/FOR/DELT,XTIME,ITIME,ISTEP,ISMP,ITAPE,TRV                        0008000
                9*       DIMENSION WORK1(M),WORK2(N)                                             0009000
               10*       DO 10 J=1,N1                                                            0010000
               11*       DO 20 I=1,M                                                             0011000
               12*    20 WORK1(I)=DR2(I)/AMAX1(1.,VR2(I,J))                                      0012000
               13*       MIN=MINMAG(WORK1)+1                                                     0013000
               14*       DT=WORK1(MIN)*0.9                                                       0014000
               15*       DT=AMIN1(DT,DELT)                                                       0015000
               16*    10 CONTINUE                                                                0016000
               17*       DT=AMIN1(DT,TRV)                                                        0017000
               18*       IF(DT.GE.DELT)RETURN                                                    0018000
               19*       DELT=0.75*DELT                                                          0019000
               20*       PRINT 100,DELT                                                          0020000
               21*   100 FORMAT(//////,'********DELT IS CHANGED TO',1PE11.2,' **********')       0021000
               22*       RETURN                                                                  0022000
               23*       END                                                                     0023000
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CARD IMAGE FILE EDITOR(CIFEM) -- VERSION 05.29  DATE=10/26/82       TIME=14:16:32:36

*** MEMBER ADVECT

      1*       SUBROUTINE ADVECT                                                      0001000
      2* C                                                                           0002000
      3* C                    COMPLTE THE ADVECTIVE TERMS                            0003000
      4* C                                                                           0004000
      5*       PARAMETER M=21,N=21                                                    0005000
      6*       PARAMETER M1=M-1,M2=M-2,N1=N-1,N2=N-2                                  0006000
      7*       COMMON/ONE/VR1(M,N1),VT1(M,N1),B1(M1,N1),VR2(M,N1),                    0007000
      8*      1           VT2(M,N1),B2(M1,N1),VR3(M,N1),VT3(M,N1),                    0008000
      9*      2           B3(M1,N1),P(M1,N1),VZ(M1,N)                                 0009000
     10*       COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N)     0010000
     11*       COMMON/THR/RHO,KH0R(N1),BV2(N),ALPHA,BNDA,BNDB,CORI,G,HK(M),ZK(N)      0011000
     12*       DIMENSION VR(M,N1),VT(M,N1),B(M1,N1)                                   0012000
     13*       EQUIVALENCE (VR,VR2),(VT,VT2),(B,B2)                                   0013000
     14* C                                                                           0014000
     15* C                    HORIZONTAL ADVECTION FOR RADIAL VELOCITY               0015000
     16* C                                                                           0016000
     17*       DO 10 J=1,N1                                                           0017000
     18*       DO 10 I=2,M1                                                           0018000
     19*    10 VR3(I,J)=-0.25*((VR(I,J)+VR(I-1,J))*(VR(I,J)-VR(I-1,J))/DR1(I-1)       0019000
     20*      1          +(VR(I+1,J)+VR(I,J))*(VR(I+1,J)-VR(I,J))/DR1(I))            0020000
     21*      2          +VR3(I,J)                                                   0021000
     22* C                                                                           0022000
     23* C                    HORIZONTAL ADVECTION FOR TANGENTIAL VELOCITY           0023000
     24* C                                                                           0024000
     25*       DO 20 J=1,N1                                                           0025000
     26*       DO 20 I=2,M1                                                           0026000
     27*    20 VT3(I,J)=-0.25*((VR(I,J)+VR(I-1,J))*(VT(I,J)-VT(I-1,J))/DR1(I-1)       0027000
     28*      1          +(VR(I+1,J)+VR(I,J))*(VT(I+1,J)-VT(I,J))/DR1(I))            0028000
     29*      2          +VT3(I,J)                                                   0029000
     30* C                    HORIZONTAL ADVECTION FOR BUOYANCY                      0030000
     31* C                                                                           0031000
     32*       DO 60 J=1,N1                                                           0032000
     33*       DO 60 I=2,M2                                                           0033000
     34*    60 B3(I,J)=B3(I,J)-0.5*(VR(I,J)*(B(I,J)-B(I-1,J))/DR2(I)                  0034000
     35*      1          +VR(I+1,J)*(B(I+1,J)-B(I,J))/DR2(I+1))                      0035000
     36*       DO 70 J=1,N1                                                           0036000
     37*    70 B3(1,J)=B3(1,J)-0.5*VR(2,J)*(B(2,J)-B(1,J))/DR2(2)                     0037000
     38*       DO 80 J=1,N1                                                           0038000
     39*    80 B3(M1,J)=B3(M1,J)-0.5*VR(M1,J)*(B(M1,J)-B(M2,J))/DR2(M1)               0039000
     40* C                                                                           0040000
     41* C                    VERTICAL ADVECTION FOR RADIAL VELOCITY                 0041000
     42* C                                                                           0042000
     43*       DO 90 J=2,N2                                                           0043000
     44*       DO 90 I=2,M1                                                           0044000
     45*    90 VR3(I,J)=VR3(I,J)-0.25*((VZ(I-1,J)+VZ(I,J))*(VR(I,J)-VR(I,J-1))       0045000
     46*      1          /DZ2(J)+(VZ(I,J+1)+VZ(I-1,J+1))*(VR(I,J+1)-VR(I,J))        0046000
     47*      2          /DZ2(J+1))                                                  0047000
     48*       DO 95 I=2,M1                                                           0048000
     49*    95 VR3(I,1)=VR3(I,1)-0.25*(VZ(I,2)+VZ(I-1,2))*(VR(I,2)-VR(I,1))          0049000
     50*      1          /DZ2(2)                                                     0050000
     51*       DO 96 I=2,M1                                                           0051000
     52*    96 VR3(I,N1)=VR3(I,N1)-0.25*(VZ(I-1,N1)+VZ(I,N1))*(VR(I,N1)-VR(I,N2))    0052000
     53*      1          /DZ2(N1)                                                    0053000
     54* C                                                                           0054000
     55* C                    VERTICAL ADVECTION FOR TANGENTIAL VELOCITY             0055000
     56* C                                                                           0056000
     57*       DO 100 J=2,N2                                                          0057000
     58*       DO 100 I=2,M1                                                          0058000
     59*   100 VT3(I,J)=VT3(I,J)-0.25*((VZ(I-1,J)+VZ(I,J))*(VT(I,J)-VT(I,J-1))       0059000
     60*      1          /DZ2(J)+(VZ(I,J+1)+VZ(I-1,J+1))*(VT(I,J+1)-VT(I,J))        0060000
     61*      2          /DZ2(J+1))                                                  0061000
     62*       DO 105 I=2,M1                                                          0062000
     63*   105 VT3(I,1)=VT3(I,1)-0.25*(VZ(I,2)+VZ(I-1,2))*(VT(I,2)-VT(I,1))          0063000
     64*      1          /DZ2(2)                                                     0064000
     65*       DO 106 I=2,M1                                                          0065000
     66*   106 VT3(I,N1)=VT3(I,N1)-0.25*(VZ(I,N1)+VZ(I-1,N1))*(VT(I,N1)-VT(I,N2))    0066000
     67*      1          /DZ2(N1)                                                    0067000
     68* C                                                                           0068000
     69* C                    VERTICAL ADVECTION FOR B                               0069000
     70* C                                                                           0070000
     71*       DO 150 J=2,N2                                                          0071000
     72*       DO 150 I=1,M1                                                          0072000
     73*   150 B3(I,J)=B3(I,J)-0.5*(VZ(I,J)*(B(I,J)-B(I,J-1))/DZ2(J)                 0073000
     74*      1          +VZ(I,J+1)*(B(I,J+1)-B(I,J))/DZ2(J+1))                      0074000
     75*       DO 160 I=1,M1                                                          0075000
     76*   160 B3(I,1)=B3(I,1)-0.5*VZ(I,2)*(B2(I,2)-B2(I,1))/DZ2(2)                  0076000
     77*       DO 170 I=1,M1                                                          0077000
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CARD IMAGE FILE EDITOR(CIFER) -- VERSION 05.29  DATE=10/26/82       TIME=14:16:32:36

*** MEMBER ADVECT

      170 B3(I,N1)=B3(I,N1)+0.5*VZ(I,N1)*(B(I,N1)-B(I,N2))/DZ2(N1)                0078000
C                                                                                 0079000
C                     INERTIA TERMS FOR HORIZONTAL MOMENTUM                       0080000
C                                                                                 0081000
      DO 110 J=1,N1                                                               0082000
      DO 110 I=2,M1                                                               0083000
      VR3(I,J)=VR3(I,J)+VT(I,J)*(VT(I,J)/R1(I)+CORI)                              0084000
  110 VT3(I,J)=VT3(I,J)-VR(I,J)*(VT(I,J)/R1(I)+CORI)                              0085000
C                                                                                 0086000
C                       PRESSURE GRADIENT FORCE                                   0087000
C                                                                                 0088000
      DO 120 J=1,N1                                                               0089000
      DO 120 I=2,M1                                                               0090000
  120 VR3(I,J)=VR3(I,J)-(P(I,J)-P(I-1,J))/(RHO*DR2(I))                            0091000
C                                                                                 0092000
C                       STRATIFICATION TERM                                       0093000
C                                                                                 0094000
      DO 130 J=1,N1                                                               0095000
      DO 130 I=1,M1                                                               0096000
  130 B3(I,J)=B3(I,J)+0.5*(VZ(I,J)*BV2(J)+VZ(I,J+1)*BV2(J+1))                     0097000
      RETURN                                                                      0098000
      END                                                                         0099000
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CARD IMAGE FILE EDITOR(CIFED) -- VERSION 05.29  DATE=10/26/82       TIME=14:16:32:30

*** MEMBER PUTOUT

      1*        SUBROUTINE PUTOUT                                                     0001000
      2*        PARAMETER M=21,N=21                                                   0002000
      3*        PARAMETER M1=M-1,M2=M-2,N1=N-1,N2=N-2                                 0003000
      4*        COMMON/ONE/VR1(M,N1),VT1(M,N1),B1(M1,N1),VR2(M,N1),                   0004000
      5*       1           VT2(M,N1),B2(M1,N1),VR3(M,N1),VT3(M,N1),                   0005000
      6*       2           B3(M1,N1),P(M1,N1),VZ(M1,N)                                0006000
      7*        COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N)    0007000
      8*        COMMON/THR/RHO,RHOR(N1),BV2(N),ALPHA,BNDA,BNDB,CORI,G,RK(M),ZK(N)     0008000
      9*        COMMON/FOR/DELT,XTIME,ITIME,ISTEP,ISW6,ITAPE,TBV                      0009000
     10* C                                                                            0010000
     11* C                    THIS SUBROUTINE PRINT OUT FIELDS FOR A QUICK LOOK        0011000
     12* C                                                                            0012000
     13*        DIMENSION IDUM(M,N)                                                   0013000
     14*    700 FORMAT(////,'  RADIAL VELOCITY (CM/S) AT T=',I6,' H')                 0014000
     15*    705 FORMAT(////,'  TANGENTIAL VELOCITY (CM/S) AT T=',I6,' H')             0015000
     16*    710 FORMAT(////,'  VERTICAL VELOCITY (CM/S) AT T=',I6,' H')               0016000
     17*    715 FORMAT(////,'  BUOYANCY FIELD (*.001) AT T=',I6,' H')                 0017000
     18*    725 FORMAT(////,'  PRESSURE (*10 DYNE/CM**2) AT TIME=',I6,' H')          0018000
     19*    720 FORMAT(1H1,////,20X,'**********   OUTPUT AT TIME =',I6,' H    OR',   0019000
     20*       1 F8.2,' DAY     ISTEP =',I7,'    **********')                       0020000
     21*        DAY=TIME/86400.+0.0001                                                0021000
     22*        PRINT 720,ITIME,DAY,ISTEP                                             0022000
     23*        DO 10 J=1,N1                                                          0023000
     24*        DO 10 I=1,M                                                           0024000
     25*     10 IDUM(I,J)=VR2(I,J)                                                    0025000
     26*        PRINT 700,ITIME                                                       0026000
     27*        CALL MAP(IDUM,R1,Z2,M,N1)                                             0027000
     28*        DO 20 J=1,N1                                                          0028000
     29*        DO 20 I=1,M                                                           0029000
     30*     20 IDUM(I,J)=VT2(I,J)                                                    0030000
     31*        PRINT 705,ITIME                                                       0031000
     32*        CALL MAP(IDUM,R1,Z2,M,N1)                                             0032000
     33*        DO 30 J=1,N                                                           0033000
     34*        DO 30 I=1,M1                                                          0034000
     35*     30 IDUM(I,J)=VZ(I,J)                                                     0035000
     36*        PRINT 710,ITIME                                                       0036000
     37*        CALL MAP(IDUM,R2,Z1,M1,N)                                             0037000
     38*        DO 40 J=1,N1                                                          0038000
     39*        DO 40 I=1,M1                                                          0039000
     40*     40 IDUM(I,J)=B2(I,J)*1.E3                                                0040000
     41*        PRINT 715,ITIME                                                       0041000
     42*        CALL MAP(IDUM,R2,Z2,M1,N1)                                            0042000
     43*        DO 50 J=1,N1                                                          0043000
     44*        DO 50 I=1,M1                                                          0044000
     45*     50 IDUM(I,J)=P(I,J)*1.E-1                                                0045000
     46*        PRINT 725,ITIME                                                       0046000
     47*        CALL MAP(IDUM,R2,Z2,M1,N1)                                            0047000
     48*        RETURN                                                                0048000
     49*        END                                                                   0049000
```

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CARD IMAGE FILE ECITAR(CIFER) ** VERSION 05.29  DATE=10/26/82        TIME=14:11:32.36

*** MEMBER MAP

                1*        SUBROUTINE MAP(A,R,Z,MM,NN)                                    0001000
                2*        PARAMETER MB=21,NB=21                                          0002000
                3*        DIMENSION R(MM),Z(NN)                                          0003000
                4*        INTEGER A (M,N),IR(M),IZ(N)                                    0004000
                5*     70 FORMAT(1HS,7X,25I5)                                            0005000
                6*     80 FORMAT(1HS,I4,3X,25I5)                                         0006000
                7*        MP=MIN0(25,MM)                                                 0007000
                8*        DO 10 I=1,MP                                                   0008000
                9*     10 IR(I)=R(I)+1.E-5+0.1                                           0009000
               10*        DO 20 J=1,NN                                                   0010000
               11*     20 IZ(J)=Z(J)+1.E-5+0.1                                           0011000
               12*        PRINT 70                                                       0012000
               13*        PRINT 70,(IR(I),I=1,MP)                                        0013000
               14*        PRINT 70                                                       0014000
               15*        DO 30 JJ=1,NN                                                  0015000
               16*        J=NN+1-JJ                                                      0016000
               17*     30 PRINT 80,IZ(J),(A(I,J),I=1,MP)                                 0017000
               18*        RETURN                                                         0018000
               19*        END                                                            0019000
```

END

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